Adams 220.5
v. 2

Adams 220.5 v.a

CONTENTS

OF THE

SIXTH ESSAY.

CHAP. I.

THE Subject of this Eſſay curious and intereſting in a very high degree.—All the Comforts, Conveniencies, and Luxuries of Life, are procured by the Aſſiſtance of FIRE *and of* HEAT.*—The Waſte of Fuel very great.—Importance of the Economy of Fuel to Individuals, amd to the Public.—Means uſed for eſtimating the Amount of the Waſte of Fuel.—An Account of the firſt Kitchen of the Houſe of Induſtry at Munich, and of the Expence of Fuel in that Kitchen compared with the* [illegible] *ſumed in the Kitchens of private Famil*[illegible] *ccount of ſeveral other Kitchens conſtr*[illegible] *arious Principles at Munich, under the Direction of* [illegible] *Author.—Introduction to a more ſcientific In*[illegible] *gation of the Subject under conſideration.* 1

CHAP. II.

Of the GENERATION OF HEAT *in the* COMBUS[illegible] OF FUEL.*—Without knowing what Heat* [illegible] *is, the Laws of its Action may be inveſtigat*[illegible] *Probability that the Heat generated in the Co*[illegible]

10985/4

tion of Fuel is furniſhed by the Air, and not by the Fuel.—Effects of blowing a Fire explained.—Of Fire-places in which the Fire is made to blow itſelf.—Of Air-furnaces.—Theſe Fire-places illuſtrated by a Lamp on Argand's *Principle.—Great Importance of being able to regulate the Quantity of Air*
enters a cloſed Fire-place.—Utility of Damp-
Chimnies of cloſed Fire-places.—General
tions for conſtructing cloſed Fire-
plac
xplanation of the Principles
n which
are founded. Page 35

CHAP. III.

CONFINING HEAT, *and* DIRECT-
ATIONS.—*Of Conductors and Non-*
Heat.—Common Atmoſpheric Air a
uctor of Heat, and may be employed
vantage for confining it—is employed
that Purpoſe, in many Inſtances—is
incipal Cauſe of the Warmth of Natural and
icial Clothing—is the ſole Cauſe of the Warmth
ible Windows.—Great Utility of Double
Walls—they are equally uſe-
s in Cold.—ALL ELASTIC
rs of Heat.—STEAM *proved by Experiment to be a Non-conductor of Heat.—*
a Non-conductor of Heat. 50

CHAP. IV.

ANNER *in which* HEAT *is* COMMUNI-
y FLAME *to other Bodies.—Flame acts on*
the ſame Manner as a hot Wind.—The

Effect of a Blow-pipe in increaſing the Activity of Flame explained, and illuſtrated by Experiments.—A Knowledge of the Manner in which Heat is communicated by Flame neceſſary in order to determine the moſt advantageous Form for Boilers.—General Principles on which Boilers of all Dimenſions ought be conſtructed. - Page 66

CHAP. V.

An Account of Experiments made with Boilers and Fire-places of various Forms and Dimenſions; together with Remarks and Obſervations on their Reſults, and on the Improvements that may be derived from them.—An Account of ſome Experiments made on a very large Scale in a Brew-houſe Boiler.—An Account of a Brew-houſe Boiler conſtructed and fitted up on an improved Plan.—Reſults of ſeveral Experiments which were made with this new Boiler.—Of the Advantage in regard to the Economy of Fuel in boiling Liquids, which ariſes from performing that Proceſs on a large Scale.—Theſe Advantages are limited.—An Account of an Alteration which was made in the new Brew-houſe Boiler, with a view to the SAVING OF TIME *in cauſing its Contents to boil.—Experiments ſhowing the Effects produced by theſe Alterations.—An Eſtimate of the* RELATIVE QUANTITIES OF HEAT *producible from* COAKS—PIT-COAL—CHARCOAL, *and* OAK.—*A Method of eſtimating the Quantity of Pit-coal which would be neceſſary to perform any of the Proceſſes mentioned in this Eſſay, in which Wood was uſed*

as

as Fuel.—An Eſtimate of the TOTAL QUANTITIES *of Heat producible in the Combuſtion of different Kinds of Fuel; and of the real Quantities of Heat which are loſt, under various Circumſtances, linary Proceſſes.* - Page 76

CHAP. VI.

Account of a Number of Kitchens, public and te, and Fire-places for various Uſes, which been conſtructed under the Direction of the r, in different Places.—Of the Kitchen of HOUSE *of* INDUSTRY *at* MUNICH—*Of that the* MILITARY ACADEMY—*Of that of the* LITARY MESS-HOUSE—*That of the* FARM-USE, *and thoſe belonging to the* INN *in the* IGLISH GARDEN *at* MUNICH.—*Of the Kitens of the Hoſpitals of* LA PIETA *and* LA MIRICORDIA *at* VERONA.—*Of a ſmall Kitchen ted up as a Model in the Houſe of* SIR JOHN INCLAIR *Bart. in* LONDON.—*Of the Kitchen f the* FOUNDLING HOSPITAL *in* LONDON.—*Of* MILITARY KITCHEN *for the Uſe of* TROOPS *in* CAMP.—*Of a* PORTABLE BOILER *for the Uſe of* TROOPS *on a* MARCH.—*Of a large* BOILER *fitted up as a Model for* BLEACHERS *at the* LINEN-HALL *in* DUBLIN.—*Of a Fire-place for* COOKING, *and at the ſame Time* WARMING A LARGE HALL; *and of a* PERPETUAL OVEN, *both fitted up in the* HOUSE *of* INDUSTRY *at* DUBLIN.—*Of the* KITCHEN—LAUNDRY—CHIMNEY FIRE-PLACES—COTTAGE FIRE-PLACE—*and Model of a* LIME-KILN—*fitted up in* IRELAND *in the Houſe of the* DUBLIN SOCIETY. - 142

DESCRIPTION *of the* PLATES. - 187

ESSAY VI.

OF

THE MANAGEMENT OF FIRE,

AND

THE ECONOMY OF FUEL.

ESSAY VI.

CHAP. I.

The Subject of this Eſſay curious and intereſting in a very high degree.—All the Comforts, Conveniencies, and Luxuries of Life, are procured by the Aſſiſtance of FIRE *and of* HEAT.—*The Waſte of Fuel very great.—Importance of the Economy of Fuel to Individuals, and to the Public.—Means uſed for eſtimating the Amount of the Waſte of Fuel.—An Account of the firſt Kitchen of the Houſe of Induſtry at Munich, and of the Expence of Fuel in that Kitchen, compared with the Quantity conſumed in the Kitchens of private Families.—An Account of ſeveral other Kitchens conſtructed on various Principles at Munich, under the Direction of the Author.—Introduction to a more ſcientific Inveſtigation of the Subject under conſideration.*

NO ſubject of philoſophical inquiry, within the limits of human inveſtigation, is more calculated to excite admiration, and to awaken curioſity, than FIRE; and there is certainly none more extenſively uſeful to mankind. It is owing, no doubt, to our being acquainted with it from our infancy, that we are not more ſtruck with its appearance, and more ſenſible of the benefits we derive from it. Almoſt every comfort and convenience which man by his ingenuity procures for himſelf, is obtained by its aſſiſtance; and he is not more diſtinguiſhed from the brute creation by the uſe of ſpeech, than by his power over that wonderful agent.

Having long been accuſtomed to conſider the Management of Heat as a matter of the higheſt importance to mankind, a habit of attending carefully to every circumſtance relative to this intereſting ſubject that occaſionally came under my obſervation, ſoon led me to diſcover how much this ſcience has been neglected, and how much room there is for very eſſential improvements in almoſt all thoſe various operations in which heat is employed for the purpoſes of human life.

The great waſte of Fuel in all countries muſt be apparent to the moſt curſory obſerver; and the uſes to which Fire is employed are ſo very extenſive, and the expence for Fuel makes ſo conſiderable an article in the liſt of neceſſaries, that the importance of the ſubject cannot be denied.

And with regard to the Economy of Fuel, it has this in particular to recommend it, that whatever is ſaved by an individual, is at the ſame time a poſitive ſaving to the whole community; for the leſs demand there is for any article in the market, the lower will be its price; and as all the ſubjects of uſeful induſtry—all the arts and manufactures, without exception, depend, directly or indirectly, on operations in which Fire is neceſſary, it is of much importance to a manufacturing and commercial country to keep the price of Fuel as low as poſſible:—And even in countries where there are no manufactures, and where the inhabitants ſubſiſt entirely by agriculture, if wood be uſed as Fuel—as the proportion of woodland to arable muſt depend in a great meaſure on the conſumption of fire-wood, any ſaving of Fuel will be attended with a proportional diminution of the foreſts reſerved for fire-wood,—conſequently, with an increaſe of the lands under cultivation,—with an increaſe of inhabitants,—and of national wealth, ſtrength, and proſperity.

But what renders this ſubject peculiarly intereſting, is the great relief to the poor in all countries, and particularly in all cold climates, and in all great cities in every climate, that would reſult from any conſiderable diminution of the price of Fuel, or from any ſimple contrivance by which a ſmaller quantity of this neceſſary article than they now are obliged to employ to make themſelves comfortable, might be made to perform the ſame ſervices. Thoſe who have never been expoſed to the inclemencies of the ſeaſons,—who have never been eye-witneſſes to the ſufferings of the poor in their miſerable habitations, pinched with cold and ſtarving with hunger,—can form no idea of the importance *to them* of the ſubject which I propoſe to treat in this Eſſay.

To all thoſe who take pleaſure in doing good to mankind by promoting uſeful knowledge, and facilitating the means of procuring the comforts and conveniencies of life, theſe inveſtigations cannot but be very intereſting.

Though it is generally acknowledged that there is a great waſte of Fuel in all countries, ariſing from ignorance and careleſſneſs in the management of Fire, yet few—very few, I believe—are aware of the real amount of this waſte.

From the reſult of all my inquiries upon this ſubject, I have been led to conclude, that not leſs than *ſeven-eighths* of the heat generated, or which, *with proper management*, *might be generated*, from Fuel actually conſumed, is carried up into the atmoſphere with the ſmoke, and totally loſt. And this opinion has not been formed haſtily; on the contrary, it is the reſult of much attentive obſervation, and of many experiments. But, in a matter of ſo much importance, I feel it to be my duty not merely to give the Public my *opinions*, but to lay before them the grounds upon which thoſe opinions have been founded; in order that every one may judge for himſelf of the certainty, or probability, of my deductions.

It would not be difficult, merely from a conſideration of the nature of heat,—of the manner in which it is generated in the combuſtion of Fuel, and the manner in which it exiſts when generated,—to ſhew that, as the proceſs of boiling is commonly performed, there muſt of neceſſity be a very great loſs of heat; for when the veſſel, in which the fluid to be boiled is contained, is placed over an open or naked fire, not only by far the greater part of the radiant heat is totally loſt, but alſo of that which exiſts in the flame, ſmoke, and hot vapour, a very ſmall proportion only enters the veſſel; the reſt going off with great rapidity, by the chimney, into the higher regions of the atmoſphere. But, without inſiſting upon theſe reaſonings, (though they are certainly incontrovertible,) I ſhall endeavour to eſtabliſh the facts in queſtion upon ſtill more ſolid ground—that of actual experiment.

In the proſecution of the experiments neceſſary in this inveſtigation, I proceeded in the following manner:—As the quantity of heat which any given quantity of any given kind of Fuel is capable of generating, is not known, there is no fixed ſtandard with which the reſult of an experiment can be compared, in order to aſcertain exactly the proportion of the heat ſaved, or uſefully employed, to that loſt: Inſtead therefore of being able to determine this point *directly*, I was obliged to have recourſe to *approximations*. Inſtead of determining the quantity of heat loſt in any given operation, I endeavoured to find out with how much leſs Fuel the ſame operation might be performed, by a more advantageous arrangement of the Fire, and diſpoſition of the machinery: And ſeveral extenſive public eſtabliſhments, which have been erected in Bavaria within theſe laſt ſix or ſeven years, under my direction, by order of His Moſt Serene Highneſs the ELECTOR PALATINE; particularly an eſtabliſhment for the Poor of Munich (of which an account has been given to the Public in my firſt Eſſay); and the Eſtabliſhment of a Public Academy for the education of 180 young men, deſtined for the ſervice of the ſtate in the different civil and military departments;—the economical arrangements of theſe eſtabliſhments afforded me a moſt favourable opportunity of putting into practice all my ideas relative to the Management of Fire; and of aſcertaining, by numerous experiments made upon a large ſcale, and often varied and repeated, the real importance of the improvements I have introduced.

That many experiments have been actually made in theſe two Eſtabliſhments, during the ſeven years they have exiſted, will not be doubted by thoſe who are informed, that the Kitchen, or rather the Fire-place of the kitchen of the Houſe of Induſtry, has been pulled down and built entirely anew no leſs than *three times*, and that of the Military Academy *twice*, during that period; and that the forms of the boilers, and the internal conſtruction of the fire-places, have been changed ſtill oftener.

The importance of the improvements in the management of heat employed in culinary operations, which have reſulted from theſe inveſtigations, will appear by comparing the quantity of Fuel now actually uſed in thoſe kitchens, to that conſumed in performing the ſame operations in kitchens on the common conſtruction: And this will at the ſame time ſhew, in a clear and ſatisfactory manner, what I propoſed to prove,—namely, that in all the common operations in which Fire is employed, there is a very great waſte of Fuel.

The waſte of Fuel in boiling water or any other liquid over an open fire, in the manner in which that proceſs is commonly performed, and the great ſaving of Fuel which will reſult from a more advantageous diſpoſition and management of the Fire, will be evident from the reſults of the following Experiments, all of which were made by myſelf, and with the utmoſt care.

Experiment, No. 1.

A copper boiler belonging to the kitchen of the Military Academy in Munich, 22 Rhinland inches in diameter above, 19¼ inches in diameter below, and 24 inches in depth, and which weighed 50 lbs. weight of Bavaria, (= 61.92 lbs. avoirdupois,) being fixed in its fire-place, was filled with 95 Bavarian meaſures (= 28 Engliſh wine-gallons) of water, which weighed 187 Bavarian pounds (= 232.58 lbs. avoirdupois); and this water being at the temperature of 58° F. a fire was lighted under the boiler with dry beech-wood, and the water was made to boil, and was continued boiling two hours. The time employed and wood conſumed in this Experiment, were as follows:

	Time employed. Hours.	Min.		Wood conſumed. lbs.
To make the water boil, - -	1	1	—	11
To keep the water boiling, - -	2	0	—	2½
Total, -	3	1	—	13½

Experi-

Experiment, No. 2.

The ſame boiler, containing the ſame quantity of water at the ſame temperature, being now removed to the kitchen of a private gentleman in the neighbourhood, (Baron de Schwachheim, a brother of the Commandant of the Academy,) and placed upon a tripod, a quantity of the ſame kind of wood uſed in the former Experiment being provided, a fire was lighted under it by the gentleman's cook, (directions having been given to be as ſparing as poſſible of Fuel,) and it was made to boil, and continued boiling two hours.

The reſult of the Experiment was as follows:

	Time employed.			Wood conſumed.
	Hours.	Min.		lbs.
To make the water boil, - -	1	31	—	45
To keep it boiling, - -	2	0	—	17½
Total, -	3	31	—	62½.

As in theſe two Experiments the ſame boiler was employed;—as the quantity of water was the ſame,—as alſo its temperature at the beginning of the Experiments,—and as it was made to continue boiling during the ſame length of time, it is evident that the quantities of wood conſumed ſhow the relative advantages of the different methods employed in the management of the Fire. The difference of theſe quantities of Fuel is very great (the one being only 13½ lbs. and the other amounting to no leſs than $62\frac{1}{2}$ lbs.). And this ſhows how very conſiderable the waſte of Fuel really is, in the manner in which it is commonly employed for culinary purpoſes, and how important the ſavings are which may be made by introducing a more advantageous arrangement for the management of Fire. But great as theſe ſavings may appear to be, as ſhown by the reſults of the foregoing Experiments, yet they are in fact ſtill more conſiderable, as will be abundantly proved in the ſequel. In the Experiment, No. 2. in which the boiler was put over an open Fire, great care was taken to place the Fuel in the moſt advantageous manner; but, in general, little attention is paid to that circumſtance, and the waſte of Fuel is greatly increaſed by ſuch negligence: But in cloſed fire-places, upon a good conſtruction, as the *proper place* for the Fuel cannot be miſtaken, and as it is fixed, and bounded on all ſides by a wall, the ignorance or inattention of thoſe who take care of the Fire can never be productive of any great waſte of Fuel; and this is an advantage of no ſmall importance attending theſe fire-places.

Experiment, No. 3.

A large copper ſauce-pan or *caſſerole*, 11$\frac{1}{4}$ inches in diameter above,—10$\frac{3}{4}$ in diameter below, and 3$\frac{3}{4}$ inches deep, containing 4 meaſures of water, weighing 7$\frac{15}{16}$ lbs. and at the temperature of 58° F. being placed in its cloſed fire-place, and a fire being made under it with ſmall pieces of dry beech-wood cut in lengths of about 4 inches, the water was made to boil, and was continued boiling two hours.

The reſult of the Experiment was as follows:

	Time employed.			Wood conſumed.
	Hours.	Min.		lbs.
To make the water boil, - -	0	12	—	1
To keep it boiling, - - -	2	0	—	0$\frac{3}{4}$
Total,	2	12	—	1$\frac{3}{4}$

Experiment, No. 4.

The ſame ſauce-pan, containing the ſame quantity of water, and at the ſame temperature as in the laſt Experiment, was now taken from its proper fire-place, and placed upon a tripod; and a fire being made under it with dry beech-wood, the reſult of the Experiment was as follows:

	Time employed.			Wood conſumed.
	Hours.	Min.		lbs.
To make the water boil, - -	0	28	—	6
To keep it boiling, - - -	2	0	—	5$\frac{1}{2}$
Total,	2	28	—	11$\frac{1}{2}$

The difference in the reſults of theſe two Experiments is nearly the ſame as that in the reſults of thoſe before mentioned, and they all tend to ſhow, that in cooking, or boiling over an open fire, nearly *five times* as much Fuel is required, as when the heat is confined in a cloſed fire-place, and its operation properly directed.

But I muſt again repeat, what I have already obſerved with reſpect to the two former Experiments, as the Experiments, No. 2. and No. 4. were both made with the utmoſt care, the reſults of them, compared with thoſe which were made with the ſame boilers placed in cloſed fire-places, can give no adequate idea of the real loſs of heat, and waſte of Fuel, which take place in the common operations of cookery.

From ſeveral eſtimates which I have made with great care relative to this ſubject, founded upon the quantity of Fuel actually conſumed in the kitchens of ſeveral private families, compared with the quantities of different kinds of food prepared for the table, it appears that at leaſt *nine-tenths* of the wood actually conſumed in common kitchens, where cooking is carried on over an open fire, might be ſaved, by introducing the various improvements I have brought into uſe in the kitchens which have been conſtructed under my directions.

But it is not alone in kitchens, in which cooking is carried on over open fires, that uſeful alterations may be made; kitchens with cloſed fire-places, and indeed all the kitchens which have yet been contrived,

trived, (as far as my knowledge extends,) are ſuſceptible of great improvement.

The various improvements that may be made in mechanical arrangements for the Economy of Fuel, will appear in a ſtriking manner from a detail of the different alterations which have from time to time been made in the kitchen of the Houſe of Induſtry at Munich, and in that of the Military Academy, and of the effects produced by thoſe progreſſive improvements.

The Houſe of Induſtry being an eſtabliſhment of public charity, and the number of thoſe fed from the kitchen amounting from 1000 to 1500 perſons daily, the Economy of Fuel, in a kitchen upon ſo large a ſcale, became an object of ſerious conſideration; and I attended to this matter with peculiar pleaſure, as it ſo completely coincided with my favourite philoſophical purſuits.

The inveſtigation of heat, and of the laws of its operations, had long occupied my attention, and I had been ſo fortunate, in the courſe of my Experiments upon that ſubject, as to make ſome diſcoveries which were thought worthy of being inſerted in the Philoſophical Tranſactions of the Royal Society of London; and for my laſt paper upon that ſubject, publiſhed in the Tranſactions for the year 1792, I had the honour to receive the annual Medal of the Society. I hope my mentioning this circumſtance will not be attributed to oſtentation. My motive in doing it, is merely to ſhow, that when I undertook to make the arrangements of which I am about to give an account, the ſubject was by no means new to me; but, on the contrary, that I was prepared, and in ſome meaſure qualified, for ſuch inveſtigation.

I conceive it to be the duty of thoſe who propoſe uſeful improvements for the benefit of mankind, not only to *merit*, but alſo to do every thing in their power to *obtain*, the confidence of thoſe to whom their propoſals are ſubmitted; and there appears to me to be a much greater degree of pride and arrogance diſplayed by an author *in taking it for granted* that the world is already ſufficiently acquainted with his merit and his qualifications to treat the ſubject he undertakes to inveſtigate, than in modeſtly pointing out the grounds upon which the confidence of the Public in his knowledge of his ſubject, and in his integrity, may be founded.

But to return from this digreſſion. In the firſt arrangement of the kitchen in the Houſe of Induſtry at Munich, which was finiſhed in the beginning of the year 1790, eight large copper boilers, each capable of containing about 38 Engliſh wine gallons, were placed in ſuch a manner in two rows, in a ſolid maſs of brick-work, 3 feet high, 9 feet wide, and 18 feet long, built in the middle of the kitchen, that, from a ſingle fire-place, ſituated at one end of this brick-work, by means of canals (furniſhed with valves or dampers) going from it, through the ſolid maſs of the brick-work to all the different boilers, theſe boilers were all heated, and made to boil with one ſingle fire; and though none of them were in actual contact with the fire-place, and ſome of them were diſtant from it near 15 feet, yet they were all heated with great facility, and in a ſhort ſpace of time, by the heat which, upon opening the valves, (which were of iron,) was made to paſs through the canals.

Each boiler having its ſeparate canal, and its ſeparate valves, any ſingle boiler, or any number of them, might be heated at pleaſure, without heating the reſt; and by opening the valves of any boiler more or leſs, more or leſs heat, as the occaſion required, might be made to paſs under the boiler;—and when no more heat was wanting for any of the boilers, or when the fire was too ſtrong, by opening a particular valve, a communication with a waſte-canal was formed, by which all the heat, or any part of it at pleaſure, might be made to paſs off directly into the chimney, without going near any of the boilers.

The Fire was regulated by a regiſter in the door of the aſh-pit, by which the air was admitted into the fire-place; and, when no more heat was wanted, the Fire was put out by cloſing this regiſter entirely, and by cloſing at the ſame time all the valves or dampers in the canals leading from the fire-place.

The fire-place was of an oval form, 3 feet long, 2 feet 3 inches wide, and about 18 inches high, vaulted above with *a double vault*, 4 inches of air being left between the two vaults; and the Fuel was introduced into the fire-place by a paſſage cloſed by a *double* iron door, which door was kept conſtantly ſhut;—and the Fuel was burnt upon an iron grate; the air which ſupplied the Fire coming up from below the grate through the aſh-pit.

The loſs of heat in its paſſage from the fire-place to the boilers, was prevented by making the canals of communication *double*, one within the other; the internal canal by which the heat paſſed, and which was 5 inches wide internally, and 6 inches high, being itſelf placed, and, as it were, *inſulated*, in a canal ſtill larger, in ſuch a manner that the canal by which the heat paſſed, (which was conſtructed of very thin bricks, or rather tiles,) was *ſurrounded on every ſide* with a wall, 2 inches thick, of *confined air*. The ſurrounding canal being formed in the ſolid body of the maſs of brick-work, this arrangement of the double canals was entirely concealed. The double canals and the double vault over the fire-place were intended to ſerve the ſame purpoſe, namely, *to confine more effectually the heat*, and prevent its eſcape into the maſs of brick-work, and its conſequent loſs.

Having found, in the courſe of my Experiments, that confined air is the beſt barrier * that can be oppoſed to heat, to confine it I endeavoured to avail myſelf of that diſcovery in theſe economical arrangements, and my attempts were not unſucceſsful.

Not only the fire-place itſelf, and the canals of communication between the fire-place and the boilers,

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* See Philoſophical Tranſactions, 1792, Part I.

ers, were ſurrounded by confined air, but it was alſo made uſe of for confining the heat in the boilers, and preventing its eſcaping into the atmoſphere. This was done by making the covers of the boilers *double*. Theſe covers, (See the figures 1 and 2, Plate I.) which were made of tin, or rather of thin iron-plates tinned, were in the form of a hollow cone; the height of the cone was equal to about one-third of its diameter; and the air which it contained was entirely ſhut up, the bottom of the cone being cloſed by a circular plate or thin ſheet of tinned iron. The bottom of the cone was accurately fitted to the top of the boiler, which it completely cloſed by means of a rim about 2 inches wide, which entered the boiler; which rim was ſoldered to the flat ſheet of tinned iron which formed the bottom of the cover. The ſteam, generated by the boiling liquid, was carried off by a tube about half an inch in diameter, which paſſed through the hollow conical cover, and which was attached to the cover, both above and below, with ſolder, in ſuch a manner that the air with which the hollow cone was filled, remained completely confined, and cut off from all communications with the external air of the atmoſphere, as well as with the ſteam generated in the boiler.

In ſome of the covers I filled the hollow of the cone with fur; but I did not find that theſe were ſenſibly better for confining the heat than thoſe in which the cone was filled ſimply with air.

To convince the numerous ſtrangers, who from curioſity viſited this kitchen, of the great advantage of making uſe of double covers to confine the heat in the boilers, inſtead of uſing ſingle covers for that purpoſe, a ſingle cover was provided, which, as it was externally of the ſame form as the others, when it was placed upon a boiler, could not be diſtinguiſhed from them; but as its bottom was wanting, and conſequently there was no confined air interpoſed between the hot ſteam in the boiler and the external ſurface of the cover, on being placed upon a kettle actually boiling, this cover inſtantaneouſly became ſo exceedingly hot as actually to burn thoſe who ventured to touch it;—while a *double cover*, formed of the ſame materials, and placed in the ſame ſituation, was ſo moderately warm that the naked hand might be held upon it for any length of time without the leaſt inconvenience.

As it was eaſy to conceive that what was ſo exceedingly hot as to burn the hand, in an inſtant, upon touching it, could not fail to communicate a great deal of heat to the cold atmoſphere, which continually lay upon it, this Experiment ſhowed, in a ſtriking and *convincing* manner, the utility of my double covers; and I have ſince had the ſatiſfaction to ſee them gradually finding their way into common uſe.

It is perhaps quite unneceſſary that I ſhould inform my readers, that one principal motive which induced me to take ſo much pains in the arrangement of this kitchen, was a deſire to introduce uſeful

ful improvements relative to the Management of Heat and the Economy of Fuel, into common practice. An eſtabliſhment ſo intereſting in all reſpects,—ſo important in its conſequences,—and ſo perfectly new in Bavaria, as a public Houſe of Induſtry upon a liberal and extenſive plan,—where almoſt every trade and manufacture is carried on under the ſame roof,—where the poor and indigent of both ſexes, and of all ages, find a comfortable aſylum, and employment ſuited to their ſtrength and to their talents; and where induſtry is excited, *not by puniſhments*, but by *the moſt liberal rewards*, and by the kindeſt uſage: Such an eſtabliſhment, I thought, could not fail to excite the curioſity of the Public, and to draw together a great concourſe of viſitors; and as this appeared to me a favorable opportunity to draw the public attention to uſeful improvements, all my meaſures were taken accordingly; and not only the kitchen, but alſo the bakehouſe,—the ſtoves for heating the rooms,—the lamps,—the various utenſils and machines made uſe of in the different manufactories,—all the different economical arrangements and contrivances for facilitating the operations of uſeful induſtry, were ſo many models expreſsly made for imitation.

But in the arrangements relative to the Economy of Fuel, beſides a view to immediate public utility, another motive, not much leſs powerful, contributed to induce me to pay all poſſible attention to the ſubject; namely, a deſire to acquire a more thorough knowledge relative to the nature of Heat, and of the laws of its operations; and with this view ſeveral parts were added to the machinery, which I ſuſpected at the time to be too complicated to be really uſeful in common practice.

The ſteam, for inſtance, which aroſe from the boiling liquids, inſtead of being ſuffered to eſcape into the atmoſphere, was carried up by tubes into a room immediately over the kitchen, where it was made to paſs through a ſpiral worm, placed in a large caſk full of cold water, and condenſed, giving out its heat to the water in the caſk; which water thus warmed, without any new expence of Fuel, was made uſe of next day, inſtead of cold water, for filling the boilers. That this water, ſo warmed, might not be cooled during the night, the caſk that contained it was put into another caſk ſtill larger; and the ſpace between the two caſks was filled with wool. The cooling of the ſteam, in its paſſage from the boiler to the caſk where it was condenſed, was prevented by warm coverings of ſheep-ſkins with the wool on them, by which the tubes of communication, which were of tin, were defended from the cold air of the atmoſphere.

By this contrivance, the heat, which would otherwiſe have been carried off by the ſteam into the atmoſphere and totally loſt, was arreſted in its flight, and brought back into the boiler, and made to work the ſecond day.

By other contrivances, the ſmoke alſo was laid under contribution. After it had paſſed under the boilers, and juſt as it was about to eſcape by the chimney, it was ſtopped; and, by being made to paſs under a large copper filled with cold water, was deprived of the greater part of the heat it ſtill retained: And thinking it probable that conſiderable advantages would be derived from drying the wood very thoroughly, and even heating it, before it was made uſe of for Fuel, the ſmoke from two of the boilers was made to paſs under a plate of iron which formed the bottom of an oven, in which the wood, neceſſary for the conſumption of the kitchen for one day, (having previouſly been cut into billets of a proper ſize,) was dried during 24 hours, previous to its being uſed.

In a ſmaller kitchen, (adjoining to that I have been deſcribing,) which was conſtructed merely as a model for imitation, and which was conſtantly open for the inſpection of the Public, five boilers of different ſizes, all heated by the ſame fire, were placed in a ſemicircular maſs of brick-work, and the ſmoke, after having paſſed under all theſe five boilers, was made to heat, at pleaſure, either an oven, or water which was contained in a wooden caſk ſet upright upon the brick-work.—A tube of copper, tinned on the outſide, which went through the caſk, gave a paſſage to the ſmoke, and this tube was connected with the bottom of the caſk by means of a circular plate of copper through which the tube paſſed, which plate cloſed a circular opening in the bottom of the caſk ſomewhat larger in diameter than the tube.

This circular plate was nailed to the bottom of the caſk, and the joining made water-tight by interpoſing between the metallic plate and the wood a ſheet of paſteboard; and the tube was faſtened to the plate with ſolder. This tube, (which was about 6 inches in diameter,) as ſoon as it had paſſed the circular plate, and entered the barrel, branched out into three ſmaller tubes, each about 4 inches in diameter, which, running parallel to each other through the whole length of the caſk, went out of it above, by three different holes in the upper head of the caſk, and ended in a canal which led to the chimney.

This tube, by which the ſmoke paſſed through the caſk, was branched out into a number of branches in order to increaſe the ſurface, by which the heat of the ſmoke was communicated to the water in the caſk. The caſk was ſupplied with water from a reſervoir placed in the upper part of the building, by means of a leaden pipe of communication from the one to the other; and the machinery was ſo contrived, that, when any water was drawn out of the caſk for uſe, it was immediately replaced from the reſervoir; but as ſoon as the water in the caſk had regained its proper height, the cold water from the reſervoir ceaſed to flow in it.

Nothing more generally excited the ſurpriſe and curioſity of thoſe who viſited this kitchen, than to ſee water actually boiled in a wooden caſk, and drawn from it, boiling hot, by a braſs cock. I have been the more particular in deſcribing the manner in which this was done, as I have reaſon to think that a contrivance of this kind, or ſomething ſimilar to it, might, in many caſes, be applied to uſeful purpoſes. No contrivance can poſſibly be invented by which heat can be communicated to fluids with ſo little loſs; and as wood is not only an excellent non-conductor of heat itſelf, but may eaſily be ſurrounded by confined air, by furs and other like bodies which are known to be uſeful in confining heat, the loſs of heat, by the ſides of a containing veſſel compoſed of wood, might be almoſt entirely prevented.

Why ſhould not the boilers for large ſalt-works and breweries, and thoſe deſtined for other ſimilar proceſſes, in which great quantities of water are heated, or evaporated, be conſtructed of wood, with horizontal tubes of iron or of copper, communicating with the fire-place, and running through them, for the circulation of the ſmoke?—But this is not the place to enlarge upon this ſubject; I ſhall therefore leave it for the preſent, and return to my kitchens.

To prepare the ſoup furniſhed to the Poor from the kitchen of the Houſe of Induſtry, it was found neceſſary to keep up the fire near *five hours*, the ſoup, in order to its being good, requiring to be kept actually boiling above three hours.

The Fuel made uſe of in this kitchen was dry beech-wood; a cord of which, (or *klafter*, as it is called,) 5 Engliſh feet $8\frac{9}{10}$ inches long, 5 feet $8\frac{9}{10}$ inches high, and 3 feet $1\frac{1}{3}$ inches wide, and which weighed at an average about 2200 Bavarian pounds, (= 2724 lbs. Avoirdupois,) coſt at an average about $5\frac{1}{4}$ florins (= 9 s. $6\frac{1}{2}$ d. ſterling) in the market.

Of this wood the daily conſumption, when ſoup was provided for 1000 perſons, was about 300 lbs. Bavarian weight, or about $\frac{1}{7}$, or more exactly $\frac{3}{22}$ of a cord or clafter, which coſt 43 creutzers, (60 creutzers making a florin,) or about 1 s. $3\frac{1}{2}$ d. ſterling: And this gives $\frac{1}{23}$ of a creutzer, or $\frac{1}{20}$ of a farthing, for the daily expence for Fuel in cooking for each perſon.

To make an eſtimate of the daily expence for Fuel in cooking the ſame quantity of the ſame kind of ſoup in private kitchens, we will ſuppoſe theſe 1000 perſons, who were fed from the public kitchen of the Houſe of Induſtry, to be ſeparated into families of 5 perſons each.

This would make juſt 200 families; and the quantity of wood conſumed in the public kitchen daily for feeding 1000 perſons, (= 300 lbs.,) being divided among 200 families, gives $1\frac{1}{2}$ lbs. of wood for the daily conſumption of each family; and according to this eſtimate, 1 cord of wood, weighing 2200 lbs. ought to ſuffice for cooking for ſuch a family 1466 days, or 4 years and 6 days.

But upon the moſt careful inquiries relative to the real conſumption of Fuel in private families in operations of cookery, as they are now generally performed over an open fire, I find that 5 Bavarian pounds of good peas-ſoup can hardly be prepared at a leſs expence of Fuel than 15 lbs. of dry beech-wood of the beſt quality; conſequently, a cord of ſuch wood, inſtead of ſufficing for preparing a ſoup daily for a family of 5 perſons for 4 years, would hardly ſuffice for ſo long a time as 5 months.

And hence it appears, that the conſumption of Fuel in the kitchens of private families, is to that conſumed in the firſt kitchen of the Houſe of Induſtry at Munich, *in preparing the ſame quantity of the ſame kind of food*, (peas-ſoup,) as 10 to 1 *. But it muſt be remembered, that this difference in the quantities of Fuel expended is not occaſioned *entirely* by the difference between the two methods of managing the Fire; for, excluſive of the effect produced by a given arrangement of the machinery, —with the ſame arrangement, the greater the quantity of food prepared at once, or the larger the boiler, (within certain limits however, as will be ſeen hereafter,) the leſs in proportion will be the quantity of Fuel required;—and the ſaving of Fuel which ariſes from cooking upon a large ſcale is very conſiderable. But I ſhall take occaſion to treat this part of my ſubject more fully elſewhere.

The kitchen in the Houſe of Induſtry was finiſhed in the beginning of the year 1790. And much about the ſame time, two other public kitchens upon a large ſcale were erected at Munich, under my directions; namely, the kitchen belonging to the Military Academy, and that belonging to the Military Hall (as it is called) in the Engliſh garden, in which building near 200 military officers meſſed daily during the annual encampments,—for which purpoſe this building was erected.

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* Afterwards, on altering the kitchen of the Houſe of Induſtry, and fitting it up on better principles, the Economy of Fuel was carried ſtill farther, as will be ſeen in the ſequel of this Eſſay.

There is likewiſe in the garden, (which is 6 Engliſh miles in circumference,) an inn—a farm-houſe, and a large dairy; and theſe eſtabliſhments gave me an opportunity of conſtructing no leſs than four other kitchens;—namely, two for the inn, one for the farm-houſe, and one for the uſe of the dairy. And the uſes for which theſe different kitchens were deſigned, and to which they were applied, were ſo various, as not only to include almoſt every proceſs of cookery, but alſo to afford opportunities of performing the ſame operations upon very different ſcales, and conſequently of making many intereſting Experiments relative to the Management of Heat, and the Economy of Fuel.

That I did not neglect theſe opportunities of purſuing, with effect, a ſubject which had long engaged my attention, and to which I was much attached, will readily be believed by thoſe who know what ardour a curious ſubject of philoſophical inveſtigation is capable of inſpiring in an inquiſitive mind.

As the Experiments I have made, or cauſed to be made, in the different eſtabliſhments before mentioned, during the ſix or ſeven years that they have exiſted, are extremely numerous; it would take up too much time to give an account of them in detail; I ſhall therefore content myſelf with merely noticing the general reſults of them, and mentioning more particularly only ſuch of them as appear to me to be moſt important. And in regard to the peculiar conſtruction of the different kitchens above mentioned, as moſt of them have undergone many alterations, and as no one of them remains exactly in the ſame ſtate in which it was firſt conſtructed, I do not think it neceſſary to be very particular in my account of them; I ſhall occaſionally mention the principles on which they were conſtructed, and the faults I diſcovered in them; but when I ſhall come to ſpeak of thoſe improvements which have ſtood the teſt of actual experience, and which I can recommend as being worthy of imitation, I ſhall take care to be very exact and particular in my deſcriptions.

It will not be found very difficult, I fancy, from what has been ſaid, to form a pretty juſt idea of the conſtruction of the kitchen in the Houſe of Induſtry above deſcribed, even without the help of a plan or drawing of it. That in the Military Academy was conſtructed upon a different principle: Inſtead of heating all the boilers from one and the ſame fireplace, almoſt every boiler had its own ſeparate fireplace; and though the boilers were all furniſhed with double covers, ſimilar to thoſe made uſe of in the kitchen of the Houſe of Induſtry, yet there was no attempt made to recover the heat carried off by the ſteam, but it was ſuffered to eſcape without hindrance into the atmoſphere; it having been found, by the experiments made in the kitchen of the

Houſe of Induſtry, that when the Fire is properly managed, that is to ſay, when the heat is but juſt ſufficient to keep the liquid boiling hot, or *very gently boiling*, the quantity of ſteam generated is inconſiderable, and the heat carried off by it not worth the trouble of ſaving. Each fire-place was furniſhed with an iron grate, upon which the wood was burnt, and the opening into the fire, as well as that which communicated with the aſh-pit, had in each its ſeparate iron door.

Finding afterwards that the iron door which cloſed the opening by which the wood was introduced into the fire-place, was much heated, and conſequently that it cauſed a conſiderable loſs of heat by communicating it to the cold atmoſphere with which it was in contact; in order to remedy this evil without incurring the expence of double doors, the iron door was removed, and in its ſtead was placed a hollow cylinder, or rather truncated cone, of burnt clay or common earthen-ware, which cone was 4 inches long, 6 inches in diameter internally, and 8 inches in diameter externally, at its larger end or baſe; and 5½ inches in diameter internally, and 7½ inches in diameter externally, at its ſmaller end: And being firmly fixed, with its axis in an horizontal poſition, and its larger end or baſe outwards, in the middle of the opening leading to the fire-place, and being well united with the ſolid brick-work by means of mortar, the cavity of this cone formed the opening by which the wood was introduced into the fire-place. This cavity being cloſed with a fit ſtopper of earthen-ware, as earthen-ware is a non-conductor of heat, or as heat cannot paſs through it but with great difficulty, and very ſlowly, the external ſurface of this cone and its ſtopper were never much heated, conſequently the quantity of heat they could communicate to the atmoſphere was but very trifling. This contrivance was afterwards rendered much more ſimple, by ſubſtituting, inſtead of the hollow cone, a tile, 10 inches ſquare, and about 2½ inches thick, with a conical hole in its center, 6 inches in diameter externally, and 5¾ inches in diameter within, provided with a fit baked earthen ſtopper. (See the Figures, N° 6, 7, and 8. Plate I.)

A perforated ſquare tile is preferable to a hollow cylinder for forming a paſſage into the fire-place, not only becauſe it is cheaper, ſtronger, and more durable, but alſo becauſe it may, on account of its form, be more eaſily and more firmly fixed in its place, and united with the reſt of the brick-work.

If proper moulds be provided for forming theſe perforated tiles and their ſtoppers, they may be afforded for a mere trifle. In Munich they are made of the very beſt earth, by the Elector's potter, and they coſt no more than 24 creutzers, or ſomething leſs than 9 d. ſterling, for a tile with its ſtopper. I had ſeveral made of ſand-ſtone by a ſtone-cutter, but they coſt me 1 florin and 30 creutzers, or about 2 s. 9d. ſterling each.

Though thoſe made of ſtone anſwered perfectly well, yet I found them not better than thoſe made of earthen-ware; and as theſe laſt are much cheaper, and I believe equally durable, they ought certainly to be preferred. That the ſtopper may be made to fit with accuracy the hole it is intended to cloſe, (which is neceſſary, as will be ſeen hereafter,) they may be ground together with fine ſand moiſtened with water.

Senſible, from the beginning, of the great importance of being abſolutely maſter of the air which is admitted into the fire-place to feed the Fire, ſo as to be able to admit more or leſs at pleaſure, or to exclude it entirely; I took care, in all my fire-places, to cloſe very exactly the paſſage into the aſh-pit by a door carefully fitted to its frame, the air being admitted through a ſemicircular opening furniſhed with a regiſter in the middle of this door. This contrivance (which admits of no further improvement) is indiſpenſably neceſſary in all well-conſtructed fire-places, great or ſmall. (See the Figures from Fig. 9 to Fig. 16. Plate II.)

Having occaſion, in the courſe of my arrangements, to make uſe of a great number of boilers, and often of ſeveral boilers of the ſame dimenſions, I availed myſelf of that circumſtance to determine, by actual experiments, the beſt form for boilers, or that form which, with any given capacity, ſhall be beſt adapted for ſaving Fuel.

Two or more boilers of the ſame capacity, but of different forms, conſtructed of ſheet copper of the ſame thickneſs, were placed in cloſed fire-places, conſtructed as nearly as poſſible upon the ſame principles, and were uſed for a length of time in the ſame culinary proceſſes; and the quantity of Fuel conſumed by each being noted, the comparative advantages of their different forms were aſcertained. Some of theſe boilers were made deep and narrow;—others wide and ſhallow;—there were ſome with flat bottoms; others of a globular form; and others again with their bottoms drawn inward like the bottom of a common glaſs bottle. The reſults of theſe inquiries were very curious, and led me to a moſt intereſting diſcovery:—They taught me not only what forms are beſt for boilers; but alſo (what is ſtill more intereſting) *why* one form is preferable to another:—They gave me much new light with reſpect to the *manner* in which flame and hot vapour part with their heat; and ſuggeſted to me the idea of a very important improvement in the internal conſtruction of fire-places, which I have ſince put in practice with great ſucceſs.

But in order to be able to explain this matter in a clear and ſatisfactory manner, and to render it eaſier to be underſtood by thoſe who have not been much converſant in inquiries of this kind, it will be neceſſary to go back a little, and to treat the ſubject under conſideration in a more regular and ſcientific manner.

Though it was not my intention originally to write an elementary treatiſe on Heat, yet, as the firſt or fundamental principles of that ſcience are neceſſary to be known, in order to eſtabliſh upon ſolid grounds the practical rules and directions relative to the management of Heat which will hereafter be recommended, it will not, I truſt, be deemed either improper or ſuperfluous, to take a more extenſive view of the ſubject, and to treat it methodically, and at ſome length.

I have perhaps already expoſed myſelf to criticiſm, by paying ſo little attention to method in this Eſſay, as to poſtpone ſo long the inveſtigation of the elementary principles of the ſcience I have undertaken to treat.—It may be thought that the part of the ſubject I am now about to conſider ſhould have preceded all other inveſtigation;—that inſtead of occupying the middle of my book, it ought to have been diſcuſſed in the Introduction, or at leaſt to have been treated in the beginning of the firſt chapter:—But if I have been guilty of a fault in the arrangement of my ſubject, it has ariſen, not from inattention, but from an error of judgment. Deſirous rather of writing an *uſeful book*, than of being the Author of a *ſplendid performance*, I have not ſcrupled to tranſgreſs the eſtabliſhed rules of elegant compoſition in all caſes where I thought it would contribute to my main deſign, *public utility*:—And well aware that my book, in order to its being really uſeful, muſt be read by many who have neither time nor patience to labour through an elementary treatiſe upon ſo abſtruſe a ſubject, I have endeavoured to *decoy* my reader into the ſituation in which I wiſh him to be placed, in order to his having a complete view of the proſpect I have prepared for him, rather than to force him into it. If I have uſed art in doing this, he muſt forgive me; my deſign was not only innocent, but ſuch as ought to entitle me to his thanks and to his eſteem. I wiſhed to entice him on as far as poſſible, without letting him perceive the difficulties of the road; and now that we have come on together ſo far, and are ſo near our journey's end, I hope and truſt that he will not leave me.—To proceed therefore—

CHAP. II.

Of the GENERATION OF HEAT *in the* COMBUSTION OF FUEL.—*Without knowing what Heat really is, the Laws of its Action may be inveſtigated.—Probability that the Heat generated in the Combuſtion of Fuel is furniſhed by the Air, and not by the Fuel.—Effects of blowing a Fire explained.—Of Fire-places in which the Fire is made to blow itſelf.—Of Air-furnaces.—Theſe Fire-places illuſtrated by a Lamp on* Argand's *Principle.—Great Importance of being able to regulate the Quantity of Air which enters a cloſed Fire-place.—Utility of Dampers in the Chimnies of cloſed Fire-places.—General Rules and Directions for conſtructing cloſed Fire-places; with a full Explanation of the Principles on which theſe Rules are founded.*

WITHOUT entering into thoſe abſtruſe and moſt difficult inveſtigations reſpecting the Nature of FIRE, which have employed the attention and divided the opinions of ſpeculative philoſophers in all ages;—without even attempting to determine whether there be ſuch a thing as an *igneous* fluid, or not;—whether what we call *Heat* be occaſioned by the accumulation, or by the increaſed action of ſuch a fluid;—or whether it ariſes merely from an increaſed motion in the component particles of the body heated, or of ſome elaſtic fluid by which thoſe particles are ſuppoſed to be ſurrounded, and upon which they are ſuppoſed to act, or by which they are ſuppoſed to be acted upon:—In ſhort, without bewildering myſelf and my reader in this endleſs labyrinth of darkneſs and uncertainty, I ſhall confine my inquiries to objects more uſeful, and which are clearly within the reach of human inveſtigation;—namely, the diſcovery of the ſenſible properties of Heat, and of the moſt advantageous methods of generating it, and of directing it with certainty and effect in thoſe various proceſſes in which it is employed in the economy of human life.

Though I do not undertake to determine *what Heat really is*, nor even to offer any opinions or conjectures relative to that ſubject; yet as Heat is evidently ſomething capable of being excited or generated, increaſed or accumulated, meaſured and transferred from one body to another; in treating the ſubject, I ſhall ſpeak of it as being *generated*, *confined*, *directed*, *diſperſed*, &c.; it being neceſſary to uſe theſe terms in order to make myſelf underſtood.

Though it is not known exactly *how much* Heat it is poſſible to produce in the combuſtion of any given quantity of any given kind of Fuel, yet it is more than probable that the quantity depends in a great meaſure on the Management of the Fire. It is likewiſe probable—I might ſay certain—that the Heat produced is furniſhed, not merely by the

Fuel, but in a great meaſure, if not entirely, by the *air* by which the Fire is fed and ſupported. It is well known that air is neceſſary to combuſtion; it is likewiſe known that the pure part of common atmoſpheric air, or that part of it (amounting to about $\frac{1}{5}$ of its whole volume) which alone is capable of ſupporting the combuſtion of inflammable bodies, undergoes a remarkable change, or is actually *decompoſed* in that proceſs; and as in this decompoſition of pure air a great quantity of heat is known to be ſet looſe, or to become redundant, it has been ſuppoſed by many, (and with much appearance of probability,) that by far the greater part, if not all the heat produced in the combuſtion of inflammable bodies, is derived from this ſource.

But whether it be the air or the Fuel which furniſhes the heat, it ſeems to be quite certain that the quantity furniſhed depends much upon *the Management of the Fire*, and that the quantity is greater as the combuſtion or decompoſition of the Fuel is more complete. In all probability, the decompoſition of the air keeps pace with the decompoſition of the Fuel.

It is well known that the conſumption of Fuel is much accelerated, and the intenſity of the heat augmented, by cauſing the air by which the combuſtion is excited, to flow into the fire-place in a continued ſtream, and with a certain degree of velocity. Hence, blowing a fire, when the current of air is properly directed, and when it is not too ſtrong, ſerves to accelerate the combuſtion, and to increaſe the heat; but when the blaſt is improperly directed, it will rather ſerve to derange and to impede the combuſtion than to forward it; and when it is too ſtrong, it will blow the Fire quite out, or totally extinguiſh it. There is no fire, however intenſe, but may be blown out by a blaſt of air, provided it be ſufficiently ſtrong, and that as infallibly as by a ſtream of cold water. Even gun-powder, the moſt inflammable perhaps of known ſubſtances, may be actually on fire at its ſurface, and yet the Fire may be blown out and extinguiſhed before the grain of powder has had time to be entirely conſumed.

This fact, however extraordinary and incredible it may appear, I have proved by the moſt unexceptionable and concluſive experiments.

Fire-places may be ſo conſtructed that the Fire may be made to blow itſelf, or—which is the ſame thing—to cauſe a current of air to flow into the Fire: And this is an object to which the greateſt attention ought to be paid in the conſtruction of all fire-places where it is not intended to make uſe of an artificial blaſt from bellows for blowing the Fire. Furnaces conſtructed upon this principle have been called *air-furnaces;* but every fire-place, and particularly every cloſed fire-place, ought to be an air-furnace, and that even were it intended to ſerve only for the ſmalleſt ſaucepan, otherwiſe it cannot be perfect.

An Argand's lamp is a fire-place upon this conſtruction; for the glaſs tube which ſurrounds the wick (and which diſtinguiſhes this lamp from all others) ſerves merely as a blower. The circular form of the wick is not eſſential; for by applying a flatted glaſs tube as a blower to a lamp with a flat or riband wick, it may be made to give as much light as an Argand's lamp; or at leaſt quite as much in proportion to the ſize of the wick, and to the quantity of oil conſumed, as I have found by actual experiment.

But it is not the light alone that is increaſed in conſequence of the application of theſe blowers;—the heat alſo is rendered much more intenſe;—and as the heat of any fire may be increaſed by a ſimilar contrivance, on that account it is that I have had recourſe to theſe lamps to aſſiſt me in explaining the ſubject under conſideration. In theſe lamps the fire-place is cloſed on all ſides, and the current of air which feeds the Fire riſes up perpendicularly from below the fire-place into the Fire. By ſurrounding the Fire on all ſides by a wall, the cold atmoſphere is prevented from ruſhing in laterally from all quarters to ſupply the place of the heated air or vapour, which, in conſequence of its increaſed elaſticity from the heat, continually riſes from the Fire, and this cauſes the current of air below (the only quarters from which it can with advantage flow into the Fire) to be very ſtrong.

But in order that a fire-place may be perfect, it ſhould be ſo contrived that the combuſtion of the Fuel, and the generation of the heat, may occaſionally be accelerated or retarded, *without adding to or diminiſhing the quantity of Fuel*; and, when the fire-place is cloſed, this may eaſily be done by means of a *regiſter* in the door which cloſes the paſſage leading to the aſh-pit;—for, as the rapidity of the combuſtion depends upon the quantity of air by which the Fire is fed, by opening the regiſter more or leſs, more or leſs air will be admitted into the fire-place, and conſequently more or leſs Fuel will be conſumed, and more or leſs heat generated in any given time, though the quantity of Fuel in the fire-place be actually much greater than what otherwiſe would be ſufficient.—Fig. 9. ſhews the form of the regiſter I commonly uſe for this purpoſe.

In order that this regiſter may produce its proper effect, a valve, or a *damper*, as it is commonly called, ſhould be placed in the chimney or canal by which the ſmoke is carried off; which damper ſhould be opened more or leſs, as the quantity of air is greater or leſs which is admitted into the fire-place. This regiſter and this damper will be found very uſeful in another reſpect, and that is, in putting out the Fire when there is no longer an occaſion for it; for, upon cloſing them both entirely, the Fire will be immediately extinguiſhed, and the half-conſumed Fuel, inſtead of being ſuffered to burn out to no purpoſe, will be ſaved.

Nearly the ſame effects as are produced by a damper may be produced without one, by cauſing the ſmoke, after it has quitted the fire-place, to deſcend ſeveral feet below the level of the grate on which the Fuel is burned, before it is permitted to go up the chimney.

There is another circumſtance of much importance which muſt be attended to in the conſtruction of fire-places; and that is, the proper diſpoſition of the Fuel; for in order that the combuſtion may go on well, it is neceſſary, not only that the Fuel be in its proper place, but alſo that it be properly diſpoſed; —that is to ſay, that the ſolid parts of the Fuel be of a juſt ſize, and that they be not placed too near each other, ſo as to prevent the free paſſage of the air between them, nor too far aſunder; and if the fire-place can be ſo contrived, that ſolid pieces of the inflamed Fuel, as they go on to be diminiſhed in ſize as they burn, may naturally fall together in the center of the fire-place without any aſſiſtance, it will be a great improvement, as I have found by experience. This may be done, in ſmall fire-places, (and in theſe it is more particularly neceſſary,) by burning the Fuel upon a grate in the form of a ſegment of a hollow ſphere, or of a diſh. (See the Figures 3 and 4. Plate I.) All thoſe I now uſe, except it be for fire-places which are very large indeed, are of this form; and where wood is made uſe of for Fuel, it is cut into ſmall billets from 4 to 6 inches in length. Inſtead of a grate of iron, I have lately introduced grates, or rather hollow diſhes or pans, of earthen ware, perforated with a great number of holes for giving a paſſage to the air.

Theſe perforated earthen pans, which are made very thick and ſtrong, are incomparably cheaper than iron grates; and judging from the experience I have had of them, I am inclined to think they anſwer even better than the grates; indeed it appears to me not difficult to aſſign a reaſon why they ought to be better.

For large fire-places I have ſometimes uſed grates, the bars of which were common bricks placed edgewiſe, and theſe have been found to anſwer very well.

As only *that part of the air* which, entering the fire-place in a proper manner, and in a juſt quantity, and coming into actual contact with the burning Fuel, *is decompoſed*, contributes to the generation of heat; it is evident that all the air that finds its way into the fire-place, *and out of it again*, without being decompoſed, is a thief;—that it not only *contributes nothing* to the heat, but being itſelf heated at the expence of the Fire, and going off *hot* into the atmoſphere by the chimney, occaſions an actual loſs of heat; and this loſs is often very conſiderable, and the prevention of it is ſuch an object, that too much attention cannot be paid to it in the conſtruction of fire-places.

When the fire-place is cloſed on all ſides by a wall, and when the opening by which the Fuel is introduced is kept cloſed, no air can preſs in laterally upon the Fire; but yet, when the grate is larger than the heap of burning Fuel, which muſt often be the caſe, a great quantity of air may inſinuate itſelf by the ſides of the grate into the fire-place, without going through the Fire: But when, inſtead of an iron-grate, a perforated hollow earthen pan is uſed, by making the bottom of the pan of a certain thickneſs, 2, 3, or 4 inches, for inſtance, and making all the air-holes point to one common center, (to the focus or center of the Fire,) this furtive entrance of cold air into the fire-place will, in a great meaſure, be prevented.

This evil may likewiſe be prevented when circular hollow iron grates are uſed, by narrowing the fire-place immediately under the grate, in the form of an inverted, truncated, hollow cone, the opening or diameter of which above being equal to the internal diameter of the circular rim of the grate, and that below (by which the air riſes to enter the fire-place) about *one-third* of that diameter. (See the Figure 5. Plate I.) This opening below, through which the air riſes, muſt be immediately under the center of the grate, and as near to it as poſſible; care muſt be taken, however, that a ſmall ſpace be left between the outſide or underſide of the iron bars which form the hollow grate, and the inſide ſurface of this inverted hollow cone, in order that the aſhes may ſlide down into the aſh-pit.

As to the form and ſize of the aſh-pit, theſe are matters of perfect indifference, provided, however, that it be large enough to give a free paſſage to the air neceſſary for feeding the Fire, and that the only paſſage into it, by which air can enter, is cloſed by a good door furniſhed with a regiſter.

The neceſſity of being completely maſter of the paſſage, by which the air enters the fire-place, has already been ſufficiently explained.

It is perhaps unneceſſary for me to obſerve, that where perforated earthen pans are uſed inſtead of iron grates, the air-holes in the pans ought to be rather ſmaller above than below, in order that they may not be choaked up by the ſmall pieces of coal, and the aſhes which occaſionally fall through them into the aſh-pit.

One great advantage attending fire-places on the conſtruction here propoſed, is, that they ſerve equally well for every kind of Fuel. Wood, pit-coal, charcoal, turf, &c. may indifferently be uſed, and all of them with the ſame facility, and with the ſame advantages; or any two, or more, of theſe different kinds of Fuel, may be uſed at the ſame time without the ſmalleſt inconvenience;—or the Fire having been lighted with dry wood, or any other very inflammable material, the heat may afterwards be kept up by cheaper or more ordinary Fuel of a more difficult and ſlow combuſtion.—Some kinds of Fuel will perhaps be found moſt advantageous for making the pot boil, and others for keeping it boiling; and a very conſiderable ſaving will probably be found to reſult from paying due attention to this circumſtance. When the fire-place is ſo contrived as to ſerve equally well for all kinds of Fuel, this may be done without the leaſt difficulty or trouble.

I have juſt ſhown, that narrowing that part of the fire-place which lies below the grate, ſerves to make the air enter the fire in a more advantageous manner. This conſtruction has another advantage, perhaps ſtill more important; the heat which is projected downwards through the openings between the bars of the grate, inſtead of being permitted to eſcape into the aſh-pit, (where it would be loſt,) ſtriking againſt the ſides of this inverted hollow *cone*, it is there ſtopped, and afterwards riſes into the fire-place again with the current of air which feeds the Fire, or it is immediately reflected by this conical ſurface, and, after two or three bounds from ſide to ſide, is thrown up againſt the bottom of the boiler.

But in order to be able to form a clear and diſtinct idea upon this ſubject, it is neceſſary to examine with care all the circumſtances attending the generation of heat in the combuſtion of inflammable bodies, and to ſee in what manner, or under what form, the heat generated manifeſts itſelf, and how it may be collected, accumulated, confined, and directed.

This opens a wide field for philoſophical inquiry; but as theſe inveſtigations are not only curious and entertaining, but alſo uſeful and important in a high degree, I truſt my reader will pardon me for requeſting his particular attention while I endeavour to do juſtice to this moſt intereſting, but, at the ſame time, moſt abſtruſe and moſt difficult part of the ſubject I have undertaken to treat.

The heat generated in the combuſtion of Fuel manifeſts itſelf in two ways; namely, in the hot vapour which riſes from the Fire, with which it may be ſaid to be *combined*, and in the calorific rays which are thrown off from the Fire in all directions.—Theſe rays may, with greater propriety, be ſaid to be *calorific*, or *capable of generating heat*, in any body by which they are *ſtopped*, than to be called hot; for when they paſs freely through any medium, (as through a maſs of air, for inſtance,) they are not found to communicate any heat whatever to ſuch medium; neither do they appear to excite any conſiderable degree of heat in bodies from whoſe ſurfaces they are reflected; and in theſe reſpects they bear a manifeſt reſemblance to the rays emitted by the ſun.

What proportion this *radiant heat* (if I may be allowed to uſe ſo inaccurate an expreſſion) bears to that which goes off from burning bodies in the ſmoke and heated vapour, is not exactly known; it is certain, however, that the quantity of heat which goes off in the heated elaſtic fluids, viſible and inviſible, which riſe from a Fire, is much greater than that which all the calorific rays united would be capable of producing. But though the quantity of *radiant heat* is leſs than that exiſting in the hot vapour, (and which, for the ſake of diſtinction, may be called *combined heat*,) the former is ſtill much too conſiderable to be neglected.

That the heat generated, or excited, by the calorific rays which proceed from burning bodies, is in fact conſiderable, is evident from the heat which is felt in a room warmed by a chimney Fire; for as all the heat, combined with the ſmoke and hot vapour, goes up the chimney, it is certain that the increaſe of heat in the room, occaſioned by the Fire, is entirely owing to the calorific rays thrown into it from the burning Fuel.

The activity of theſe rays may be ſhown in various ways, but in no way in a more ſtriking manner than by the following ſimple Experiment: When the Fire burns bright upon the hearth, let the arm be extended in a ſtraight line towards the center of the Fire, with the hand open, and all the fingers extended and pointing to the Fire. If the hand is not nearer the Fire than the diſtance of two or three yards, except the Fire be very large indeed, the heat will ſcarcely be perceptible; but if, without moving the arm, the wriſt be bent upwards ſo as to preſent the inſide or flat of the hand perpendicular to the Fire, the heat will not only be very ſenſibly felt, but, if the Fire be large, and if it burns clear and bright, it will be found to be ſo intenſe as to be quite inſupportable.

It is not, however, burning bodies alone that emit calorific rays. All bodies,—thoſe which are fixed and incombuſtible, as well as thoſe which are inflammable,—fluids as well as ſolids,—are found to throw off theſe rays in great abundance, as ſoon as they are heated to that degree which is neceſſary to their becoming luminous in the dark, or till they are red-hot.

Bodies even which are heated to a leſs degree than that which is neceſſary to their emitting *viſible* light, ſend off calorific rays in all directions. This is a matter of fact, which has been proved by experiment. Do all bodies, at all temperatures,—freezing mercury as well as melting iron,—continually emit theſe rays in greater or leſs quantities, or with greater or leſs velocities?—Are bodies cooled in conſequence of their emitting theſe rays?—Do theſe calorific rays always generate heat, even when the body, by which they are ſtopped or abſorbed, is hotter than that from which the rays proceeded?—But I forget that I promiſed not to involve myſelf in abſtruſe ſpeculation.—To return then:—Whatever may be the nature of the rays emitted by burning Fuel, as *one* of their *known properties* is to generate heat, they ought certainly to be very particularly attended to in every arrangement in which the Economy of Heat, or of Fuel, is a principal object in view.

As theſe calorific rays generate heat in the body by which they are *ſtopped or abſorbed*, and not in the medium through which they paſs, it is neceſſary to diſpoſe thoſe bodies which are deſigned for ſtopping them, in ſuch a manner that they may eaſily and *neceſſarily* communicate the heat they thus acquire to the body upon which it is intended that it ſhould operate.

The cloſed fire-places which I have recommended, and which will hereafter be more particularly deſcribed, will anſwer this purpoſe completely.

The Fire being cloſed in theſe fire-places, on every ſide, as well below the grate as laterally, and in ſhort every where, except where the bottom of the boiler preſents itſelf to the Fire, none of theſe rays can poſſibly eſcape; and as the materials of which the fire-place is conſtructed, (bricks and mortar,) are bad conductors of heat, but a ſmall part of the heat generated in the combuſtion of the Fuel will be abſorbed and tranſmitted by them into the interior parts of the wall, there to be diſperſed and loſt. But the confining of heat is a matter of ſufficient importance to deſerve being treated in a ſeparate Chapter.

CHAP. III.

Of the Means of CONFINING HEAT; *and* DIRECTING ITS OPERATIONS.—*Of Conductors and Non-conductors of Heat.—Common Atmoſpheric Air a good Non-conductor of Heat, and may be employed with great Advantage for confining it—is employed by Nature for that Purpoſe, in many Inſtances—is the principal Cauſe of the Warmth of Natural and Artificial Clothing—is the ſole Cauſe of the Warmth of Double Windows.—Great Utility of Double Windows and Double Walls—they are equally uſeful in Hot Countries as in Cold.*—ALL ELASTIC FLUIDS *Non-conductors of Heat.*—STEAM *proved by Experiment to be a Non-conductor of Heat.*—FLAME *is alſo a Non-conductor of Heat.*

THAT HEAT paſſes more freely through ſome bodies than through others, is a fact well known; but the cauſe of this difference in the conducting powers of bodies, with reſpect to Heat, has not yet been diſcovered.

The utility of giving a wooden handle to a tea-pot or coffee-pot of metal, or of covering its metallic handle with leather, or with wood, is well known: But the difference in the conducting powers of various bodies with regard to Heat, may be ſhown by a great number of very ſimple experiments;—ſuch as are in the power of every one to make at all times and in all places, and almoſt without either trouble or expence.

If an iron nail and a pin of wood, of the ſame form and dimenſions, be held ſucceſſively in the flame of a candle, the difference in the conducting powers of the metal and of wood will manifeſt itſelf in a manner in which there will be no room left for doubt. As ſoon as the end of the nail, which is expoſed in the flame of the candle, begins to be heated, the other end of it will grow ſo hot as to render it impoſſible to hold it in the hand without being burnt; but the wood may be held any length of time in the ſame ſituation without the leaſt inconvenience; and, even after it has taken fire, it may be held till it is almoſt entirely conſumed; for the uninflamed wood will not grow hot, and, till the flame actually comes in contact with the fingers, they will not be burnt. If a ſmall ſlip or tube of glaſs be held in the flame of the candle in the ſame manner, the end of the glaſs by which it is held will be found to be more heated than the wood, but incomparably leſs ſo than the pin or nail of metal;—and among all the various bodies that can be tried in this manner, no two of them will be found to give a paſſage to Heat through their ſubſtances with exactly the ſame degree of facility *.

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* To ſhow the relative conducting power of the different metals, Doctor Ingenhouz contrived a very pretty experiment. He took equal

To confine Heat is nothing more than to prevent its eſcape out of the hot body in which it exiſts, and in which it is required to be retained; and this can only be done by ſurrounding the hot body by ſome covering compoſed of a ſubſtance through which Heat cannot paſs, or through which it paſſes with great difficulty. If a covering could be found perfectly impervious to Heat, there is reaſon to believe that a hot body, completely ſurrounded by it, would remain hot for ever; but we are acquainted with no ſuch ſubſtance; nor is it probable that any ſuch exiſts.

Thoſe bodies in which Heat paſſes freely or rapidly, are called *Conductors* of Heat; thoſe in which it makes its way with great difficulty, or very ſlowly, *Non-conductors*, or bad Conductors of Heat. The epithets, good, bad, indifferent, excellent, &c. are applied indifferently to *conductors* and to *non-conductors*. A good conductor, for inſtance, is one in which Heat paſſes very freely; a good non-conductor is one in which it paſſes with great difficulty; and an indifferent conductor may likewiſe be called, without any impropriety, an indifferent non-conductor.

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equal cylinders of the different metals, (being ſtraight pieces of ſtout wire, drawn through the ſame hole, and of the ſame length,) and, dipping them into melted wax, covered them with a thin coating of the wax. He then held one end of each of theſe cylinders in boiling water, and obſerved how far the coating of wax was melted by the Heat communicated through the metal, and with what celerity the Heat paſſed.

Thoſe bodies which are the worſt conductors, or rather the beſt non-conductors of Heat, are beſt adapted for forming coverings for confining Heat.

All the metals are remarkably good conductors of Heat;—wood, and in general all light, dry, and ſpungy bodies, are non-conductors: Glaſs, though a very hard and compact body, is a non-conductor. Mercury, water, and liquids of all kinds, are conductors; but air, and in general all elaſtic fluids, *ſteam* even not excepted, are non-conductors.

Some experiments which I have lately made, and which have not yet been publiſhed, have induced me to ſuſpect, that *water*, mercury, and all other non-elaſtic fluids, do not permit Heat to paſs through them from particle to particle, as it undoubtedly paſſes through ſolid bodies, but that their apparent conducting powers depend eſſentially upon the extreme mobility of their parts; in ſhort, that they rather *tranſport* Heat than allow it a paſſage. But I will not anticipate a ſubject which I propoſe to treat more fully at ſome future period.

The conducting power of any ſolid body in one ſolid maſs, is much greater than that of the ſame body reduced to a powder, or divided into many ſmaller pieces: An iron bar, or an iron plate, for inſtance, is a much better conductor of Heat than iron filings; and ſaw-duſt is a better non-conductor than wood. Dry wood-aſhes is a better non-conductor than either; and very dry charcoal reduced to a fine powder is one of the beſt non-conductors known; and as charcoal is perfectly incombuſtible when confined in a ſpace where freſh air can have no acceſs, it is admirably well calculated for forming a barrier for confining Heat, where the Heat to be confined is intenſe.

But among all the various ſubſtances of which coverings may be formed for confining Heat, none can be employed with greater advantage than common atmoſpheric air. It is what Nature employs for that purpoſe; and we cannot do better than to imitate her.

The warmth of the wool and fur of beaſts, and of the feathers of birds, is undoubtedly owing to the air in their interſtices; which air, being ſtrongly attracted by theſe ſubſtances, is confined, and forms a barrier which not only prevents the cold winds from approaching the body of the animal, but which oppoſes an almoſt inſurmountable obſtacle to the eſcape of the Heat of the animal into the atmoſphere. And in the ſame manner the air in ſnow ſerves to preſerve the Heat of the earth in winter. The warmth of all kinds of artificial clothing may be ſhown to depend on the ſame cauſe; and were this circumſtance more generally known, and more attended to, very important improvements in the Management of Heat could not fail to reſult from it. A great part of our lives is ſpent in guarding ourſelves againſt the extremes of heat and of cold, and in operations in which the uſe of Fire is indiſpenſable; and yet how little progreſs has been made in that moſt uſeful and moſt important of the arts,—the Management of Heat!

Double windows have been in uſe many years in moſt of the northern parts of Europe, and their great utility, in rendering the houſes furniſhed with them warm and comfortable in winter, is univerſally acknowledged,—but I have never heard that any body has thought of employing them in hot countries to keep their apartments cool in ſummer;—yet how eaſy and natural is this application of ſo ſimple and ſo uſeful an invention!—If a double window can prevent the Heat which is *in* a room from paſſing *out of it*, one would imagine it could require no great effort of genius to diſcover that it would be equally efficacious for preventing the Heat *without* from coming *in*. But natural as this conclusion may appear, I believe it has never yet occurred to any body; at leaſt, I am quite certain that I have never ſeen a double window either in Italy, or in any other hot country I have had occaſion to viſit.

But the utility of double windows and double walls, in hot as well as in cold countries, is a matter of ſo much importance that I ſhall take occaſion to treat it more fully in another place. In the mean time, I ſhall only obſerve here, that it is the *confined air* ſhut up between the two windows, and not the double glaſs plates, that renders the paſſage of Heat through them ſo difficult. Were it owing to the increaſed thickneſs of the glaſs, a ſingle pane of glaſs twice as thick would anſwer the ſame purpoſe;

poſe; but the increaſed thickneſs of the glaſs of which a window is formed, is not found to have any ſenſible effect in rendering a room warmer.

But air is not only a non-conductor of Heat, but its non-conducting power may be greatly increaſed. To be able to form a juſt idea of the manner in which air may be rendered a worſe conductor of Heat, or, which is the ſame thing, a better non-conductor of it than it is in its natural unconfined ſtate, it will be neceſſary to conſider *the manner* in which Heat paſſes through air. Now it appears, from the reſult of a number of Experiments which I made with a view to the inveſtigation of this ſubject, and which are publiſhed in a Paper read before the Royal Society *, that though the particles of air, *each particle for itſelf*, can receive Heat from *other bodies*, or communicate it to them, yet there is no communication of Heat *between one particle of air and another particle of air*. And from hence it follows, that though air may, and certainly does, *carry off* Heat, and *tranſport it* from one place, or from one body to another, yet a maſs of air in a quieſcent ſtate, or with all its particles at reſt, *could it remain in this ſtate*,—would be totally impervious to Heat; or ſuch a maſs of air would be a perfect non-conductor.

Now if Heat paſſes in a maſs of air merely in conſequence of the motion it occaſions in that air,—if it is *tranſported*,—*not ſuffered to paſs*,—in that caſe, it is clear that whatever can obſtruct and impede the internal motion of the air, muſt tend to diminiſh its conducting power: And this I have found to be the caſe in fact. I found that a certain quantity of Heat which was able to make its way through a wall, or rather a ſheet of confined air $\frac{1}{2}$ an inch thick in 9$\frac{3}{5}$ minutes, required 21$\frac{2}{5}$ minutes to make its way through the ſame wall, when the internal motion of this air was impeded by mixing with it $\frac{1}{56}$ part of its bulk of eider-down,—of very fine fur, or of fine ſilk, as ſpun by the worm.

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* See the Philoſophical Tranſactions, 1792.

But in mixing bodies with air, in order to impede its internal motion, and render it more fit for confining Heat, ſuch bodies only muſt be choſen as are themſelves non-conductors of Heat, otherwiſe they will do more harm than good, as I have found by experience. When, inſtead of making uſe of eider-down, fur, or fine ſilk, for impeding the internal motion of the confined air, I uſed an equal volume of exceedingly fine ſilver-wire flatted, (being the ravellings of gold or ſilver lace,) the paſſage of the Heat through the barrier, ſo far from being impeded, was remarkably facilitated by this addition; the Heat paſſing through this compound of air and fine threads of metal much ſooner than it would have made its way through the air alone.

Another circumſtance to be attended to in the choice of a ſubſtance to be mixed with air, in order to form a covering or barrier for confining Heat, is the fineneſs or ſubtility of its parts; for the finer they are, the greater will be their ſurface in proportion to their ſolidity, and the more will they impede the motions of the particles of the air. Coarſe horſe-hair would be found to anſwer much worſe for this purpoſe than the fine fur of a beaver, though it is not probable that there is any eſſential difference in the chymical properties of thoſe two kinds of hair.

But it is not only the fineneſs of the parts of a ſubſtance, and its being a non-conductor, which render it proper to be employed in the formation of covering to confine Heat;—there is ſtill another property, more occult, which ſeems to have great influence in rendering ſome ſubſtances better fitted for this uſe than others; and this is a certain attraction which ſubſiſts between certain bodies and air. The obſtinacy with which air adheres to the fine fur of beaſts and to the feathers of birds, is well known; and it may eaſily be proved that this attraction muſt aſſiſt very powerfully in preventing the motion of the air concealed in the interſtices of thoſe ſubſtances, and conſequently in impeding the paſſage of Heat through them.

Perhaps there may be another ſtill more hidden cauſe which renders one ſubſtance better than another for confining Heat. I have ſhown by a direct and unexceptionable Experiment, that Heat can paſs through the Torricellian vacuum *, though with rather more difficulty than in air (the con-

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* See my Experiments on Heat, publiſhed in the Philoſophical Tranſactions, vol. lxxvi.

ducting power of air being to that of a Torricellian vacuum as 1000 to 604, or as 10 to 6, very nearly); but if Heat can paſs where there is no air, it muſt in that caſe paſs by a medium more ſubtile than air;—a medium which moſt probably pervades all ſolid bodies with the greateſt facility, and which muſt certainly pervade either the glaſs or the mercury employed in making a Torricellian vacuum.

Now, if there exiſts a medium more ſubtile than air, by which Heat may be conducted, is it not poſſible that there may exiſt a certain affinity between that medium and ſenſible bodies? a certain attraction or coheſion by means of which bodies in general, or ſome kinds of bodies in particular, may, ſome how or other, impede this medium in its operations in conducting or tranſporting Heat from one place to another?—It appeared from the reſult of ſeveral of my Experiments, of which I have given an account in detail in my paper before mentioned, publiſhed in the year 1786 in the LXXVIth Vol. of the Philoſophical Tranſactions, that the conducting power of a Torricellian vacuum is to that of air as 604 to 1000:—but I found by a ſubſequent Experiment, (ſee my ſecond Paper on Heat, publiſhed in the Philoſophical Tranſactions for the year 1792,)—that 55 parts in bulk of air, with 1 part of fine raw ſilk, formed a covering for confining Heat, the conducting power of which was to that of air as 576 to 1284; or as 448 to 1000. Now, from the reſult of this laſt-mentioned Experiment, it ſhould ſeem that the introduction into the ſpace through which the Heat paſſed, of ſo ſmall a quantity of raw ſilk as $\frac{1}{56}$ part of the volume, or capacity of that ſpace, rendered that ſpace (which now contained 55 parts of air and 1 part of ſilk) more impervious to Heat than even a Torricellian vacuum.—The ſilk muſt therefore not only have completely deſtroyed the conducting power of the air, but muſt alſo at the ſame time have very ſenſibly impaired that of the etherial fluid which probably occupies the interſtices of air, and which ſerves to conduct Heat through a Torricellian vacuum: For a Torricellian vacuum was a better conductor of Heat, than this medium, in the proportion of 604 to 448. But I forbear to enlarge upon this ſubject, being ſenſible of the danger of reaſoning upon the properties of a fluid whoſe exiſtence even is doubtful; and feeling that our knowledge of the nature of Heat, and of the manner in which it is communicated from one body to another, is much too imperfect and obſcure to enable us to purſue theſe ſpeculations with any proſpect of ſucceſs or advantage.

Whatever may be the *manner* in which Heat is communicated from one body to another, I think it has been ſufficiently proved that it paſſes with great difficulty through confined air; and the knowledge of this fact is very important, as it enables us to take our meaſures with certainty and with facility for confining Heat, and directing its operations to uſeful purpoſes.

But atmoſpheric air is not the only non-conductor of Heat. All kinds of air, artificial as well as natural, and in general all elaſtic fluids, *ſteam not excepted*, ſeem to poſſeſs this property in as high a degree of perfection as atmoſpheric air.

That ſteam is not a conductor of Heat, I proved by the following Experiment: A large globular bottle being provided, of very thin and very tranſparent glaſs, with a narrow neck, and its bottom drawn inward ſo as to form a hollow hemiſphere about 6 inches in diameter; this bottle, which was about 8 inches in diameter externally, being filled with cold water, was placed in a ſhallow diſh, or rather plate, about 10 inches in diameter, with a flat bottom formed of very thin ſheet braſs, and raiſed upon a tripod, and which contained a ſmall quantity (about $\frac{2}{10}$ of an inch in depth) of water; a ſpirit lamp being then placed under the middle of this plate, in a very few minutes the water in the plate began to boil, and the hollow formed by the bottom of the bottle was filled with clouds of ſteam, which, after circulating in it with ſurpriſing rapidity 4 or 5 minutes, and after forcing out a good deal of air from under the bottle, began gradually to clear up. At the end of 8 or 10 minutes (when, as I ſuppoſed, the air remaining with the ſteam in the hollow cavity formed by the bottom of the bottle, had acquired nearly the ſame temperature as that of the ſteam) theſe clouds totally diſappeared; and, though the water continued to boil with the utmoſt violence, the contents of this hollow cavity became ſo perfectly inviſible, and ſo little appearance was there of ſteam, that, had it not been for the ſtreams of water which were continually running down its ſides, I ſhould almoſt have been tempted to doubt whether any ſteam was actually generated.

Upon lifting up for an inſtant one ſide of the bottle, and letting in a ſmaller quantity of cold air, the clouds inſtantly returned, and continued circulating ſeveral minutes with great rapidity, and then gradually diſappeared as before. This Experiment was repeated ſeveral times, and always with the ſame reſult; the ſteam always becoming viſible when cold air was mixed with it, and afterwards recovering its tranſparency when, part of this air being expelled, that which remained had acquired the temperature of the ſteam.

Finding that cold air introduced under the bottle cauſed the ſteam to be partially condenſed, and clouds to be formed, I was deſirous of ſeeing what viſible effects would be produced by introducing a cold ſolid body under the bottle. I imagined that if ſteam was a conductor of Heat, ſome part of the Heat in the ſteam paſſing out of it into the cold body, clouds would of courſe be formed; but I thought if ſteam was a *non-conductor* of Heat,—that is to ſay, *if one particle of ſteam could not communicate any part of its Heat to its neighbouring particles*, in that caſe, as the cold body could only affect the particles of ſteam *actually in contact with it*, no cloud would appear; and the reſult of the

Experiment ſhowed that ſteam is in fact a *non-conductor of Heat*; for, notwithſtanding the cold body uſed in this Experiment was very large and very cold, being a ſolid lump of ice nearly as large as an hen's egg, placed in the middle of the hollow cavity under the bottle, upon a ſmall tripod or ſtand made of iron wire; yet as ſoon as the clouds which were formed in conſequence of the unavoidable introduction of cold air in lifting up the bottle to introduce the ice, were diſſipated, which ſoon happened, the ſteam became ſo perfectly tranſparent and inviſible, that *not the ſmalleſt appearance of cloudineſs was to be ſeen any where*, not even about the ice, which, as it went on to melt, appeared as clear and as tranſparent as a piece of the fineſt rock cryſtal.

This experiment, which I firſt made at Florence, in the month of November 1793, was repeated ſeveral times in the preſence of Lord Palmerſton, who was then at Florence, and Monſ. de Fontana *.

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* The bottle made uſe of in this Experiment, though it appeared very large externally, contained but a very ſmall quantity of water, owing to its bottom being very much drawn inwards. As the hollow cavity under the bottom of the bottle (which, as I juſt obſerved, was nearly in the form of a hemiſphere, and 6 inches in diameter) ſerved as a receiver for confining the ſteam, which roſe from the boiling water in the plate, it may perhaps be imagined that a common glaſs receiver in the form of a bell, ſuch as are uſed in Pneumatical Experiments, might anſwer as well as this bottle; I thought ſo myſelf, but upon making the experiment I found my miſtake. A common receiver will anſwer perfectly well for confining the ſteam, but the glaſs ſoon becomes ſo hot that the drops of water which are formed upon its internal ſurface, in conſequence of the condenſation of the ſteam, inſtead of running down the ſides of the receiver in clear tranſ-

In theſe Experiments the air was not entirely expelled from under the bottle; on the contrary, a conſiderable quantity of it remained mixed with the ſteam even after the clouds had totally diſappeared, as I found by a particular Experiment made with a view to aſcertain that fact; but that circumſtance does not render the reſult of this Experiment leſs curious, on the contrary I think it tends to make it more ſurpriſing. It ſhould ſeem that neither the maſs of ſteam, nor that of air, were at all cooled by the body of ice which they ſurrounded, for if the air had been cooled, (in maſs,) it ſeems highly probable that the clouds would have returned.

The reſults of theſe Experiments compared with thoſe formerly alluded to, in which I had endeavoured to aſcertain the moſt advantageous forms for boilers, opened to me an entirely new field for ſpeculation and for improvement in the Management of Fire. They ſhowed me that not only cold air, but alſo hot air, and hot ſteam, and hot mixtures of air and ſteam, are non-conductors of Heat; conſequently that the hot vapour which

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tranſparent ſtreams, form blotches and ſtreaks, which render the glaſs ſo opaque that nothing can be ſeen diſtinctly through it; and this of courſe completely fruſtrates the main deſign of the Experiment; but cold water in the bottle keeping the glaſs cool, the condenſation of the ſteam upon the ſides of the hollow cavity formed by the bottom of the bottle, goes on more regularly, and the ſtreams of water which are continually running down the ſides of the glaſs, uniting together, form one tranſparent ſheet of water, by which means every thing that goes on under the bottle may be diſtinctly ſeen.

riſes from burning Fuel, and even the *flame itſelf, is a non-conductor of Heat.*

This may be thought a bold aſſertion, but a little calm reflection, and a careful examination of the phenomena which attend the combuſtion of Fuel, and the communication of Heat by flame, will ſhow it to be well founded; and the advantages which may be derived from the knowledge of this fact are of very great importance indeed. But this ſubject deſerves to be thoroughly inveſtigated.

CHAP. IV.

Of the MANNER *in which* HEAT *is* COMMUNICATED *by* FLAME *to other Bodies.—Flame acts on Bodies in the ſame Manner as a hot Wind.—The Effect of a Blow-pipe in increaſing the Activity of Flame explained, and illuſtrated by Experiments.—A Knowledge of the Manner in which Heat is communicated by Flame neceſſary in order to determine the moſt advantageous Forms for Boilers.—General Principles on which Boilers of all Dimenſions ought be conſtructed.*

IF FLAME be merely vapour, or a mixture of air and ſteam heated red-hot, as air and ſteam are both non-conductors of heat, there ſeems to be no difficulty in conceiving that Flame may, notwithſtanding its great degree of heat, ſtill retain the properties of its component fluids, and remain *a non-conductor of heat*. The non-conducting power of air does not appear to be at all impaired by being heated to the temperature of boiling water; and I ſee no reaſon why that property in air, or in any other elaſtic fluid, ſhould be impaired by any augmentation of temperature however great. If ſteam, or if air, at the temperature of 212 degrees of Fahrenheit's thermometer, be a non-conductor of of heat, why ſhould it not remain a non-conductor at that of 1000 degrees, or when heated red-hot? I confeſs I do not ſee how a body *could* be deprived of a property ſo eſſential, without being at the ſame time totally changed; and I believe nobody will imagine that either air or ſteam undergo any chymical change merely by being heated to the temperature of red-hot iron. But without inſiſting upon theſe reaſonings, however concluſive I may think them, I ſhall endeavour to ſhow, from experiment and obſervation, in ſhort to *prove*, that Flame is in fact a non-conductor of heat.

Taking it for granted,—what I imagine will not be denied,—that air is a non-conductor of heat, at leaſt in the ſenſe I have uſed that appellation, I ſhall endeavour to ſhow that Flame acts preciſely in the ſame manner as a hot wind would do in communicating heat, and in no other way; and if I ſucceed in this, I fancy I may conſider the propoſition as ſufficiently proved.

The effect of a blaſt of cold air in cooling any hot body expoſed to it is well known, and the cauſes of this effect may eaſily be traced to that property of air which renders it a non-conductor of heat; for if the particles of cold air in contact with a hot body, could, with perfect facility, give the heat they acquire from the hot body to other particles of air by which they are immediately ſurrounded, and theſe again to others, and ſo on, the heat would be carried off *as faſt as the hot body could part with it*, and any motion of the particles of the air,—any wind, or blaſt, would not ſenſibly facilitate or haſten the cooling of the body; and by a parity of reaſoning it may be ſhown, that if Flame were in fact a perfect conductor of heat, any cold body plunged into it would always be heated *as faſt as that body could receive heat*; and neither any motion of the internal parts of the Flame, nor the velocity with which it impinged againſt the cold body, could have any ſenſible effect either to facilitate or accelerate the heating of the body. But if Flame be a non-conductor of heat, its action will be exactly ſimilar to that of a hot wind, and conſequently much will depend upon the manner in which it is applied to any body intended to be heated by it.—Thoſe particles of it *only* which are in *actual contact* with the body will communicate heat to it; and the greater the number of different particles of the Flame which are brought into contact with it, the greater will be the quantity of heat communicated: Hence the importance of cauſing the Flame to impinge with force againſt the body to be heated, and to ſtrike it in ſuch a manner that its current may be broken, and that whirlpools may be formed in it; for the rapid motion of the Flame cauſes a quick ſucceſſion of hot particles; and admitting our aſſumed principles to be true, it is quite evident that every kind of internal motion among the particles of the Flame by which it can be agitated, muſt tend very powerfully to accelerate the communication of the heat.

The effect of a blow-pipe is well known, but I do not think that the *manner* in which it increaſes the *action* of *Flame*, has ever been ſatisfactorily explained. It has generally been imagined, I believe, that the current of freſh air which is forced through the Flame by a blow-pipe actually increaſes the quantity of heat; I rather ſuppoſe it does little more than direct the heat *actually exiſting in the Flame* to a given point. A current of air cannot *generate* heat, without at the ſame time being decompoſed; and in order to its being decompoſed in a fire, it muſt be brought into actual contact with the burning Fuel, or at leaſt with the uninflamed inflammable vapour which riſes from it:— But can it be ſuppoſed that there can be any thing inflammable, and not actually inflamed, in the clear, bright, and perfectly tranſparent Flame of a wax candle?—A blow-pipe has however as ſenſible an effect, when directed againſt the clear Flame of a wax candle, as when it is employed to increaſe the action of a common glaſs-worker's lamp.

Conceiving that the diſcovery of the *manner* in which the current of air from a blow-pipe ſerves to increaſe the intenſity of the action of the Flame, could not fail to throw much light upon the ſubject under conſideration,—namely, the inveſtigation of *the manner* in which heat is communicated to bodies by Flame,—I made the following Experiments, the reſults of which I conceive to be deciſive.

Concluding that the current of air from a blow-pipe, directed againſt the Flame of any burning body, could tend to increaſe the intenſity of the action of the Flame only in one or both of theſe two ways, namely, by increaſing its *action* upon the body againſt which it is directed; or by actually increaſing the *quantity* of heat generated in the combuſtion of the Fuel; a method occurred to me by which I thought it poſſible to determine, by actual experiment, to which of theſe cauſes the effect in queſtion is owing, or how much each of them might contribute to it. To do this I filled a large bladder, containing above a gallon, with *fixed air*, which, as is well known, is totally unfit for ſupporting the combuſtion of inflammable bodies, and which, of courſe, could not be ſuſpected of *adding* any heat to a Flame againſt which a current of it ſhould be directed; I imagined therefore that if a blow-pipe ſupplied with this air, on being directed againſt the Flame of a candle, ſhould be found to produce nearly the ſame effect as when common air is uſed for the ſame purpoſe, it would prove to a demonſtration that the augmentation of the intenſity of the action, or activity of the Flame which ariſes from the uſe of a blow-pipe, is owing to the agitation of the Flame,—to its being directed to a point,—to the impetuoſity with which it is made to ſtrike againſt the body which is heated by it,—and to the rapid ſucceſſion of freſh particles of this hot vapour, and not to any *poſitive increaſe of heat*.

A blow-pipe being attached to the bladder containing fixed air, the end of this pipe was directed to the clear brilliant flame of a wax candle, which had juſt been ſnuffed; and, by compreſſing the bladder, the Flame was projected againſt a ſmall tube of glaſs, which was very ſoon made red-hot, and even melted.

Having repeated this experiment ſeveral times, and having found how long it required to melt the tube when the Flame of the candle was forced againſt it by a blaſt of *fixed air*, I now varied the experiment, by making uſe of common atmoſpheric air, inſtead of fixed air; taking care to employ the ſame candle and the ſame blow-pipe uſed in the former experiments, and even making uſe of the bladder, in order that the experiments being exactly ſimilar, and differing only in the kinds of air made uſe of, the effect of that difference might be diſcovered and eſtimated.

The reſults of theſe experiments were moſt perfectly concluſive; and proved in a deciſive manner, that the effect of a blow-pipe, *when applied to clear Flame*, ariſes not from any real augmentation of heat, but merely from the increaſed activity of the Flame, in conſequence of its being impelled with force, and broken in eddies on the ſurface of the body againſt which it is made to act; the effect of the blow-pipe in theſe experiments being to all appearance quite as great when fixed air was made uſe of, (which *could not* increaſe the quantity of heat,) as when atmoſpheric air was uſed.

But conceiving the determination of this queſtion relative to the manner in which Flame communicates heat, to be a matter of much importance, I did not reſt my inquiries here: I repeated the experiments very often, and varied them in a great number of different ways; ſometimes making uſe of fixed air; ſometimes of atmoſpheric air; and at other times uſing dephlogiſticated air; and common air rendered unfit for the ſupport of animal life and of combuſtion, by burning a candle in it till the candle went out.

It would take up too much time to give an account in detail of all theſe experiments; I ſhall therefore content myſelf with merely obſerving, that they all tended to ſhow that the effect of a blow-pipe *uſed in the manner here deſcribed*, is owing to the direction and velocity it gives to the Flame againſt which it is employed, and not to any real increaſe of heat.

It muſt be remembered that the principal object I had in view in theſe experiments was to diſcover the *manner* in which Flame communicates heat to other bodies, and by what means that communication may be facilitated.—Were it required to increaſe the intenſity of the heat by *blowing the fire*, the current of air muſt be applied in ſuch a manner as to expedite the combuſtion; it muſt be directed to the inflamed ſurface of the burning Fuel, and not to the red-hot vapour or flame which riſes from it, and in which the combuſtion is moſt probably already quite complete; and in this caſe there is no doubt but the effect produced by blowing would depend much upon the quality of the air made uſe of.

The reſults of the foregoing experiments with the blow-pipe will, I am confident, be thought quite concluſive by thoſe who will take the trouble to conſider them attentively,—and the advantages that may be derived from the knowledge of the fact eſtabliſhed by them are very obvious. If Flame, or the hot vapour which riſes from burning bodies, be a non-conductot of heat;—and if, in order to communicate its heat to any other body, it be neceſſary that its particles *individually* be brought into actual contact with that body; it is evident that the form of a boiler, and of its fire-place, muſt be matters of much importance; and that *that form* muſt be moſt advantageous, which is beſt calculated to produce an internal motion in the Flame, and to bring alternately as many of its particles as poſſible into contact with the body which is to be heated by it. The boiler muſt not only have as large a ſurface as poſſible, but it muſt be of ſuch a form as to cauſe the Flame which embraces it—to impinge againſt it with force—to break againſt it—and to play over its ſurface in eddies and whirlpools.

It is therefore againſt the *bottom* of a boiler, and not againſt its ſides, that the principal efforts of the Flame muſt be directed; for when the Flame, or hot vapour, is permitted to riſe freely by the vertical ſides of a boiler, it ſlides over its ſurface very rapidly, and there being no obſtacle in the way to break the Flame into eddies and whirlpools, it glides quietly on like a ſtream of water in a ſmooth canal; and the ſame hot particles of this vapour which happen to be in immediate contact with the ſides of the boiler at its bottom or lower extremity, being continually preſſed againſt the ſurface of the boiler as they are forced upwards by the riſing current, prevent other hot particles from approaching the boiler; ſo that by far the greateſt part of the heat in the Flame and hot vapour which riſe from the Fire, inſtead of entering the boiler, goes off into the atmoſphere by the chimney, and is totally loſt.

The amount of this loſs of heat, ariſing from the faulty conſtruction of boilers and their fire-places, may be eſtimated from the reſults of the Experiments recorded in the following Chapter.

CHAP. V.

An Account of Experiments made with Boilers and Fire-places of various Forms and Dimenſions; together with Remarks and Obſervations on their Reſults, and on the Improvements that may be derived from them.—An Account of ſome Experiments made on a very large Scale in a Brew-houſe Boiler.—An Account of a Brew-houſe Boiler conſtructed and fitted up on an improved Plan.—Reſults of ſeveral Experiments which were made with this new Boiler.—Of the Advantage in regard to the Economy of Fuel in boiling Liquids, which ariſes from performing that Proceſs on a large Scale.—Theſe Advantages are limited.—An Account of an Alteration which was made in the new Brew-houſe Boiler, with a view to the SAVING OF TIME *in cauſing its Contents to boil.—Experiments ſhowing the Effects produced by theſe Alterations.—An Eſtimate of the* RELATIVE QUANTITIES OF HEAT *producible from* COAKS—PIT-COAL—CHARCOAL, *and* OAK.—*A Method of eſtimating the Quantity of Pit-coal which would be neceſſary to perform any of the Proceſſes mentioned in this Eſſay, in which Wood was uſed as Fuel.—An Eſtimate of the* TOTAL QUANTITIES *of Heat producible in the Combuſtion of different Kinds of Fuel; and of the real Quantities of Heat*

Heat which are loſt, under various Circumſtances, in culinary Proceſſes.

WHAT has been ſaid in the foregoing Chapter will, I truſt, be ſufficient to give my reader a clear and diſtinct idea of the ſubject under conſideration, in all its various details and connections,—and enable him to comprehend, without the ſmalleſt difficulty, every thing I have to add on this ſubject; and particularly to diſcover the different objects I had in view in the Experiments of which I am now about to give an account, and to judge with facility and certainty of the concluſions I have drawn from their reſults.

Theſe Experiments, though they occupy ſo many pages in this Eſſay, are but a ſmall part of thoſe I have made, and cauſed to be made under my direction, on the ſubject of Heat, during the laſt ſeven years. Were I to publiſh them all, with all their details as they are recorded in the regiſter that has been kept of them, they would fill ſeveral volumes.

It was moſt fortunate for me that this regiſter is very voluminous; for had it not been ſo, I ſhould in all probability have taken it with me to England laſt year, and in that caſe I ſhould have loſt it, with the reſt of my papers, in the trunk of which I was robbed in paſſing through St. Paul's Church-yard, on my arrival in London after an abſence of eleven years *.

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* I have many reaſons to think that theſe papers are ſtill in being;—what an everlaſting obligation ſhould I be under to the perſon who would cauſe them to be returned to me!

As I foreſaw, when I firſt began my inquiries reſpecting Heat, that I ſhould have occaſion to make many Experiments on boiling Liquids, to facilitate the regiſtering of them I formed a Table, (which I had printed,) in which, under various heads, every circumſtance relative to any common Experiment of the kind in queſtion could be entered with much regularity, and with little trouble.

As this Table may be uſeful to others who may be engaged in ſimilar purſuits, and as the publiſhing of it will alſo tend to give my reader a more perfect idea of the manner in which my Experiments were conducted, I ſhall (as an example) give an account of one Experiment, *in the ſame form* in which it was regiſtered in one of theſe printed Tables.

Theſe Tables, as they are printed for uſe, (on detached ſheets,) occupy one ſide of half a ſheet of common folio writing-paper.

AN EXPERIMENT ON THE MANAGEMENT OF FIRE IN BOILING LIQUIDS;

Made at [MUNICH], in [a Brew-houſe belonging to the Elector], the [15th] of [April 1795].

Time of the Day.		Fuel put into the Fire-place.			Contents of the Boiler.		
Hour.	Minntes.	Numb. of Pieces.	In Weight.	Temperature of the Liquid.	Kind of Liquid, &c.	Meaſures.	In Weight.
			lbs.				lbs.
9	15	29	100	60°	[Water.]	6984	12508
—	30	6	50	70°			
—	41	6	50	—			
10	5	7	50	92°			
—	25	7	50	105°			
—	46	7	50	120°			
11	0	7	50	130°			
—	15	7	50	—			
—	26	8	50	145°			
—	43	7	50	155°			
—	50	7	50	163°			
12	5	8	50	173°			
—	17	7	50	183°			
—	31	15	100	192°			
—	55	—	—	[boiled].			
1	38	7	50	—			
2	35	7	50	—			
3	38	—	—	[ceaſed boiling].			

Height of the Barometer, 26$\frac{5}{12}$ Inches; of Thermometer, 58°.

DIMENSIONS OF THE BOILER.

Diameter { above——or long—— 10 Feet.
 below——and wide—— 8 Feet.

Deep, 4 Feet.—Was conſtructed of [Copper], and weighed [not known]; contained of Water 8176 Meaſures, weighing 14643 lbs.

KIND OF FUEL USED.—[Pine-wood, Moderately dry, in Lengths of 6 Feet.]

GENERAL RESULTS OF THE EXPERIMENT.

	h.	min.
Time employed to make the Liquid boil, —	[3	40]
Fuel conſumed to make the Liquid boil, —	[800] lbs.	
	h.	min.
Time the Liquid continued to boil, — —	2	43
Fuel added to keep the Liquid boiling, —	100 lbs.	

Quantity of the Liquid evaporated [not obſerved].

PRECISE RESULT.

With the Heat generated in the Combuſtion of 1 lb. of the Fuel, [13.23 lbs.] of ice-cold Water made to boil; or [339.80 lbs.] of boiling-hot Water kept boiling 1 Hour.

Every thing in this Table, except ſuch figures and words as are printed between crochets, is contained in the printed forms: Hence it is evident how much theſe Tables tend to diminiſh the trouble of regiſtering the reſults of Experiments of this kind, and alſo to prevent miſtakes.

The example I have here given is an account of an Experiment, in which a very large quantity of water, equal to 15,590 lbs. Avoirdupois in weight, or 1866 wine gallons of 231 cubic inches each; but it is evident that theſe Tables anſwer equally well for the ſmall quantity contained by the ſmalleſt ſaucepan.

The height of the barometer is expreſſed in Paris inches; that of the thermometer in degrees of Fahrenheit's ſcale.—The other meaſures, as well of length as of capacity, are the common meaſures of the country (Bavaria); and the weight is expreſſed in Bavarian pounds, of which 100 make 123.84 lbs. Avoirdupois.

What is entered under the head of GENERAL RESULTS OF THE EXPERIMENT, requires no explanation; but what I have called the PRECISE RESULT muſt be explained.

Having frequent occaſion to compare the reſults of Experiments made at different times and in different ſeaſons of the year, as the temperature of the water in the Boiler when the fire is lighted under it is ſeldom the ſame in any two Experiments, and as the boiling heat varies with the variations of the preſſure of the atmoſphere, or of the height of the mercury in the barometer, it became neceſſary to make proper allowances for theſe differences. This I thought could beſt be done by determining, by computation, from the number of degrees the water was *actually heated*, and the quantity of Fuel conſumed in heating it that number of degrees, how much Fuel would have been required to have it heated 180 degrees, or from the point of freezing to that of boiling water (the boiling point being taken equal to the temperature indicated by 212° of Fahrenheit's thermometer, which is the boiling point under the mean preſſure of the atmoſphere at the ſurface of the ſea): Then, by dividing the weight of the water uſed in the Experiment, (expreſſed in pounds,) by the weight of the Fuel expreſſed in pounds neceſſary to heat it 180 degrees, or from the temperature of freezing to that of boiling water; this gives the number of pounds of ice-cold water which (according to the reſult of the given Experiment) *might have been* made to boil,—with the heat generated in the combuſtion of 1 lb. of the Fuel, under the mean preſſure of the atmoſphere at the level of the ſurface of the ſea.

The city of Munich, where all the Experiments were made of which I am about to give an account, being ſituated almoſt in the centre of Germany, lies very high above the level of the ſea. The mean height of the mercury in the barometer is only about 28 Engliſh inches, conſequently water boils at Munich at a lower temperature than at London. The difference is even too conſiderable to be neglected, it amounts to 2½ degrees of Fahrenheit's ſcale,—being 209½ degrees at a medium at Munich, and 212 degrees in all places ſituated near the level of the ſea. To render the reſults of my experiments and computations more ſimple and more generally uſeful, I ſhall always make due allowance for this difference.

Having, from the actual reſult of each Experiment, made a computation on the principles here deſcribed, ſhowing what (for the want of a better expreſſion) I have called the *Preciſe Reſult* of the Experiment, it is evident that theſe computations ſhow very accurately the comparative merit of the mechanical arrangements, and the management of the Fire in conducting the Experiments, in as far as relates to the Economy of Fuel; for the more ice-cold water that can be made to boil with the heat generated in the combuſtion of any given quantity (1 lb. for inſtance) of Fuel, the more perfect of courſe (other things being equal) muſt be the conſtruction of the fire-place.

Under the head of PRECISE RESULT I have ſometimes added another computation, ſhowing how much "*boiling-hot water*" might, according to the reſult of the given Experiment, be *kept boiling* "*one hour*" with the heat generated in the combuſtion of "1 lb. of the Fuel." Though I have called this a *Preciſe Reſult*, it is evident that in moſt caſes it cannot be conſidered as being very exact, owing to the difficulty of eſtimating the quantity of Fuel in the fire-place, which is *unconſumed at the moment when the water begins to boil.*

In the foregoing example, in making this computation I ſuppoſed that, when the water began to boil, there was wood enough in the fire-place *unconſumed* to keep the water boiling 43 minutes, and that the wood added afterwards (100 lb.) kept the water boiling the remainder of the time it boiled, or juſt 2 hours.

In moſt caſes, however, to ſave trouble in making theſe computations, I have ſuppoſed that all the wood employed in making the water boil is entirely conſumed in that proceſs, and that all the heat expended in *keeping the water boiling* is furniſhed by the Fuel which is added *after the water had begun to boil.* This ſuppoſition is evidently erroneous; but as the computation in queſtion can at beſt give but an inaccurate and doubtful reſult, labour beſtowed on it would be thrown away: But imperfect as theſe rough eſtimates are, they will however in many caſes be found uſeful.

In giving an account of the following Experiments, I ſhall not place them exactly in the order in which they were made, but ſhall arrange them in ſuch a manner as I ſhall think beſt, in order that the information derived from their reſults may appear in a clear point of view.

For greater convenience in referring to them, I ſhall number them all; and as I have already given numbers to the four I mentioned in the Firſt Chapter of this Eſſay, I ſhall proceed in regular order with the reſt.

Experiment, No. 5.

The firſt kitchen of the Houſe of Induſtry at Munich has already been deſcribed in the Firſt Chapter of this Eſſay; and it was there mentioned, that the daily expence of Fuel in that kitchen, when food (peas-ſoup) was prepared for 1000 perſons, amounted to 300 lb. in weight of dry beech-wood. Now as each portion of ſoup conſiſted of 1 lb., this gives 0.3 of a pound of wood for each pound of ſoup.

Experiment, No. 6.

The firſt kitchen of the Houſe of Induſtry having been pulled down, it was afterwards rebuilt on a different principle. Inſtead of Copper Boilers, Iron Boilers of a hemiſpherical form were now uſed, and each of theſe Boilers had its own ſeparate cloſed fire-place. The Boiler being ſuſpended by its rim in the brick-work, and room being left for the flame to play all round it. The ſmoke went off into the chimney by an horizontal canal, 5 inches wide and 5 inches high, which was concealed in the maſs of brick-work, and which opened into the fire-place on the ſide oppoſite to the opening by which the Fuel was introduced.

The Fire was made on a flat iron grate placed directly under the Boiler, and diſtant from its bottom about 12 inches. The aſh-pit door was furniſhed with a regiſter; but there was no damper to the canal by which the ſmoke went off into the chimney, which was a very great defect. The opening into the fire-place was cloſed by an iron door. Each of theſe Iron Boilers weighed about 148 lbs. Avoirdupois, was 25¾ Engliſh inches in diameter, and 14.935 inches deep, and contained 190½ lbs. Bavarian weight of water, equal to 235.91 lbs. Avoirdupois, or about 28¼ Engliſh wine-gallons.

From this account of the manner in which theſe Iron Boilers were fitted up, it is evident that the arrangement was not eſſentially different from that of kitchens for hoſpitals, as they are commonly conſtructed.

From Experiments made with care, and often repeated, I found that to prepare 89 portions (or 89 lbs. Bavarian weight) of peas-ſoup in one of theſe Boilers, 43 lbs. of *dry beech-wood* were required as Fuel, and that the proceſs laſted four hours and an half: This gives 0.483 of a pound of wood for each pound of the ſoup.

In the firſt arrangement of this kitchen, only 0.3 of a pound of wood was required to prepare 1 lb. of ſoup: Hence it appears that the kitchen had not been improved,—conſidered with a view to the Economy of Fuel,—by the alterations which had been made in it. This was what I expected; for the object I had in view in conſtructing this kitchen was not to ſave Fuel, but to find out how much of it is waſted in culinary proceſſes, as they are commonly performed on a large ſcale in hoſpitals and other inſtitutions of public charity.—Till I knew this, it was not in my power to eſtimate, with any degree of preciſion, the advantages of any improvements I might introduce in the conſtruction of kitchen fire-places.

To determine in how far the quantity of Fuel neceſſary in any given culinary proceſs depends on the form of *the fire-place*, (the Boiler and every other circumſtance remaining the ſame,) I made the following Experiments.

Experiments, No. 7 *and* No. 8.

Two of the Iron Boilers in the kitchen of the Houſe of Induſtry (which, as they were both caſt from the ſame model, were as near alike as poſſible) being choſen for this Experiment, one of them (No. 8.) being taken out of the brick-work, its fire-place was altered and fitted up anew on improved principles. The grate was made circular and concave, and its diameter was reduced to 12 inches; the fire-place was made cylindrical above the grate, and only 12 inches in diameter; and the Boiler being ſeated on the top of the wall of this cylindrical fire-place, the flame paſſing through a ſmall opening on one ſide of the fire-place, at the top of it, made one complete turn about the Boiler before it was permitted to go off into the canal by which the ſmoke paſſed off into the chimney.

Though there was no damper in this canal, yet as its entrance or opening, where it joined the canal which went round the Boiler, was conſiderably reduced in ſize, this anſwered (though imperfectly) the purpoſe of a damper. This fire-place being completed, and a ſmall Fire having been kept up in it for ſeveral days to dry the maſonry, the Experiment was made by preparing the ſame quantity of the ſame kind of ſoup in this, and in a neighbouring Boiler whoſe fire-place had not been altered.

The food cooked in each was 89 lb. of Peas-ſoup; and the Experiment was begun and finiſhed in both Boilers at the ſame time.

The wood employed as Fuel was pine; and it had been thoroughly dried in an oven the day before it was uſed.

The Boilers were both kept conſtantly covered with their double covers, except only when the Soup was ſtirred about to prevent its burning to the bottoms of the Boilers.

The reſult of this intereſting Experiment was as follows:

	Experiment No. 7.	Experiment No. 8.
	In the Boiler No. 1.	In the Boiler No. 8, with the improved Fire-place.
Quantity of wood conſumed in cooking 89 lbs. Bavarian weight of Peas-ſoup - - - - - -	37 lbs.	14 lbs.

Theſe Experiments were made on the 7th of November 1794. On repeating them the next day with pine-wood, which had not been previouſly dried in an oven, the reſult was as follows :

Experiments, No. 9 *and* No. 10.

	Experiment No. 9. In the Boiler No. 1.	Experiment No 10. In the Boiler No. 8, with the improved Fire-place.
Quantity of wood conſumed in cooking 89 lbs. of Peas-ſoup - -	39 lbs.	16 lbs.

The firſt remark I ſhall make on the reſults of theſe Experiments is the proof they afford, by comparing them with that which preceded them (No. 6.), of the important fact, that pine-wood affords more heat in its combuſtion than beech. This fact is the more extraordinary, as it is directly contrary to the opinion generally entertained on that ſubject ; and it is the more important, as the price of pine-wood is, in moſt places, only about half as high as that of beech, when the quantities, *eſtimated by weight*, are equal.

In the Experiment No. 6. it was found, that 43 lb. of dry beech-wood were neceſſary, when uſed as Fuel, to prepare 89 lbs. of Peas-ſoup. In the Experiment No. 7. the ſame proceſs was performed with 37 lb. and in the Experiment No. 9.

with 39 lb. of dry pine. But I ſhall have occaſion to treat this ſubject more at length in another place. In the mean time I would, however, juſt obſerve, that all my Experiments have uniformly tended to confirm the fact, that dry pine-wood affords more heat in combuſtion than dry beech. I have reaſon to think the difference is in fact greater than the Experiments before us indicate; but the *apparent* amount of it will always depend in a great meaſure on the circumſtances under which the Fuel is conſumed; or, in other words, on the conſtruction of the fire-place; and it is no ſmall advantage attending the fire-places I ſhall recommend, that they are ſo contrived as to increaſe, as much as it is poſſible, the ſuperiority of the moſt common and cheapeſt fire-wood over that which is more ſcarce and coſtly.

By comparing the reſults of theſe two ſets of Experiments (No. 7 and No. 8, No. 9 and No. 10.) an eſtimate may be made of the advantage of uſing *very dry wood* for Fuel, inſtead of making uſe of wood that has been leſs thoroughly dried; but as I mean to take an opportunity of inveſtigating that matter alſo more carefully hereafter, I ſhall not at preſent enlarge on it farther than juſt to obſerve, that as the wood, which was dried in an oven, was weighed for uſe after it had been dried, and as it certainly weighed more before it was put into the oven, the real ſaving ariſing from uſing it in this dried ſtate is not ſo great as the difference in the weights of the quantities of wood uſed in the two

Experiments. To eſtimate that ſaving with preciſion, the wood ſhould be weighed before it is dried, or in the ſame ſtate in which the other parcel of wood, which is uſed without being dried, is weighed.

But to proceed to the principal object I had in view in theſe Experiments;—the determination of the effects of the difference in the conſtruction of the two fire-places;—the difference in the quantity of Fuel expended in the two fire-places in performing the ſame proceſs, ſhows, in a manner which does not ſtand in need of any illuſtration, how much had been gained by the improvements which had been introduced.

Conceiving it to be an object of great importance to aſcertain by actual experiment, and with as much preciſion as poſſible, the real amount of the advantages, in regard to the Economy of Fuel, that may be derived from improvements in the forms of fire-places, I did not content myſelf with improving from time to time the kitchens I had conſtructed, but I took pains to determine how much I had gained by each alteration that was made. This was neceſſary, not only to furniſh myſelf with more forcible arguments to induce others to adopt my improvements, but alſo to ſatisfy myſelf with regard to the progreſs I made in my inveſtigations.

In the firſt arrangement of the kitchen of the Military Academy, the Boilers were ſuſpended by their rims in the brick-work in ſuch a manner that the flame could paſs freely all round them, and the ſmoke went off in horizontal canals which led to the chimney, but which were not furniſhed with dampers.

The Fire was made on a flat ſquare iron-grate; and the internal diameter of the fire-place was 2 or 3 inches larger than the diameter of the Boiler which belonged to it. The bottom of the Boiler was from 6 to 10, or 12 inches (according to its ſize) above the level of the grate; and the door of the opening into the fire-place, by which the Fuel was introduced, was kept conſtantly cloſed. The aſh-pit door was furniſhed with a regiſter, and the Boilers were all furniſhed with double covers.

Having, in conſequence of the progreſs I had made in my inquiries reſpecting the Management of Heat, and the Economy of Fuel, come to a reſolution to pull down this kitchen, and rebuild it on an improved principle; previous to its being demoliſhed, I made ſeveral very accurate Experiments to determine the real expence of Fuel in the fire-places as they *then exiſted*, with all their faults; and when the new arrangement of the kitchen was completed, I repeated theſe Experiments *with the ſame Boilers*; and by comparing the reſults of theſe two ſets of Experiments, I was able to eſtimate with great preciſion the real amount of the ſaving of time as well as of Fuel,—which were derived from the improvements I had introduced.

After all that has been ſaid (and perhaps already too often repeated in different parts of this Eſſay) on the conſtruction of fire-places, my reader will be able to form a clear and juſt idea of the conſtruction of thoſe of which I am now ſpeaking, (thoſe of the kitchen of the Military Academy, in its *preſent* improved ſtate,) when he is told that the Fire burns on a circular concave iron grate, about half the diameter of the circular Boiler which belongs to the fire-place; that the fire-place, properly ſo called, is a cylindrical cavity in the ſolid brick-work which ſupports the Boiler, equal in diameter to the circular grate, and from ſix to ten inches high, more or leſs according to the ſize of the Boiler; that the Boiler is *ſet down* on the top of the circular wall which forms this fire-place, a ſmall opening, from three to four or five inches in length taken horizontally, and about two or three inches high, being left on one ſide of this wall at the top of it, that the flame which burns up under the middle of the bottom of the Boiler may afterwards paſs round (in a ſpiral canal conſtructed for that purpoſe) under that part of the bottom of the Boiler which lies *without* the top of the wall of the fire-place on which the Boiler repoſes. The flame having made one complete turn *under* the Boiler in this ſpiral canal, it riſes upwards, and going once *round the ſides of the Boiler*, goes off by an horizontal canal, furniſhed with a damper, into the chimney.

In order that the top of the circular wall of the fire-place on which the Boiler is ſeated, may not cover too much of the bottom of the Boiler, its thickneſs is ſuddenly reduced *in that part* (that is to ſay, juſt where it touches the Boiler) to about half an inch.

The opening by which the Fuel is introduced into the fire-place, is a conical hole in a piece of fire-ſtone, which hole is cloſed by a fit ſtopper made of the ſame kind of ſtone. The aſh-pit door and its regiſter are finiſhed with ſo much nicety, that when they are quite cloſed the Fire almoſt inſtantaneouſly goes out.

The dimenſions of the Boiler, in which the Experiments of which I am about to give an account were made, are as follows:

Diameter	above	14.935	Inches, Engliſh meaſure.
	below	13.39	
Depth		14.52	

It weighs 37 lbs. Avoirdupois; and it contains, when quite full, about 73 lbs. Avoirdupois, equal to 8¾ gallons (wine-meaſure) of water.

In two Experiments with this Boiler, which were both made by myſelf, and in which attention was paid to every circumſtance that could tend to render them perfect, the reſults were as follows:

	Experiment No. 11. The firſt Fire-place.	Experiment No. 12. The improved Fire-place.
Quantity of water in the Boiler, in *Bavarian pounds* - - -	43.63 lbs.	43.63 lbs.
Temperature of the water in the Boiler at the beginning of the Experiment - - - -	59°	60°
Time employed in making the water boil - - - - - - -	67 min.	30 min.
Wood conſumed in making the water boil, in *Bavarian pounds*	9 lbs.	3 lbs.
Time the water continued boiling - - - - -	2 hrs. 2 min.	3 hours
Wood added to keep the water boiling - - - -	5 lbs.	2½ lbs.
Kind of wood uſed - - - -	Pine	Pine
Preciſe Reſults.		
Ice-cold water heated 180 degrees, or made to boil, with 1 lb. of wood - - - - -	4.02 lbs.	11.93 lbs.
Boiling-hot water kept boiling 1 hour, with 1 lb. of wood -	17.74 lbs.	52.36 lbs.

The following Experiments were made with two Copper Boilers, (No. 1 and No. 2.) nearly of the ſame dimenſions, in the kitchen of the Military Academy at Munich, in the preſent improved ſtate of that kitchen. Theſe Boilers are round and deep, and weigh each about 62 lbs. Avoirdupois. They belonged originally to the kitchen of the Houſe of Induſtry, being two of the eight Boilers which, in the firſt arrangement of that kitchen, were heated by the ſame Fire.

Their exact dimenſions, meaſured in Engliſh inches, are as follows:

		The Boiler No. 1.	The Boiler No. 2.
		Inches.	Inches.
Diameter	above —	22.66	22.66
	below —	19.82	20.85
Depth — —		24.72	22.04

At the beginning of each of the following Experiments, each of theſe Boilers contained juſt 95 meaſures (or *Bavarian maaſſe*) of water, weighing 187 lbs. Bavarian weight, (equal to 232.58 lbs. Avoirdupois,) or a trifle leſs than 28 gallons.

The grate on which the Fire was made under each of theſe Boilers is circular and concave, and 11 inches in diameter; and their fire-places are in all reſpects ſimilar to that juſt deſcribed (Experiment No. 11.). Both Boilers are furniſhed with double covers.

The Experiments made with the Boiler No. 1. and their reſults, were as follows:

	Experiment No. 13.	Experiment No. 14.	Experiment No. 15.	Experiment No. 16.
Quantity of water in the Boiler in the beginning of the Experiment - - -	lbs. 187	lbs. 187	lbs. 187	lbs. 187
Temperature of the water in the Boiler at the beginning of the Experiment -	61°	59°	64°	55½°
Time employed in making the water boil - - - - - -	min. 78	min. 61	min. 61	min. 62
Wood conſumed in making the water boil - - - - - -	lbs. 12	lbs. 11	lbs. 9	lbs. 8
Time the water continued to boil - -	min. 17	min. 28	min. 6	h. min. 2 19
Quantity of Fuel added to keep it boiling this time - -	—	—	—	lbs. 4
Kind of wood uſed as Fuel - - - -	Beech	Beech	Pine	Pine
Preciſe Reſults of the Experiments.				
Ice-cold water heated 180°, or made to boil, with the heat generated in the combuſtion of 1 lb. of the Fuel - -	lbs. 12.39	lbs. 14.15	lbs. 16.89	lbs. 20
Boiling water kept boiling one hour, with the heat generated in the combuſtion of 1 lb. of the wood - - - -	—	—	—	lbs. 108.40

All the foregoing Experiments were made on the ſame day, (the 13th of October 1794,) and in the ſame order in which they are numbered.

The following are the reſults of the Experiments made with the Boiler No. 2.

	Experim. No. 17.	Experim. No. 18.	Experim. No. 19.	Experim. No. 20.	Experim. No. 21.
Quantity of water in the Boiler at the beginning of the Experiment, in *Bavarian pounds* —	lbs. 187	lbs. 187	lbs. 187	lbs. 187	lbs. 187
Temperature of the water in the Boiler at the beginning of the Experiment — —	61°	58°	60°	55°	212°
Time employed in making the water boil —	min. 75	min. 55	min. 57	min. 60	—
Wood conſumed in making the water boil —	lbs. 11	lbs. 11	lbs. 9	lbs. 8	—
Time the water continued to boil — —	min. 21	min. 17	min. 8	h. min. 2 29	h. min. 1 10
Wood added to keep the water boiling — —	lb. 1	—	—	lbs. 3½	lbs. 1½
Kind of wood uſed —	Beech	Beech	Pine	Pine	Beech
Preciſe Reſults.					
Ice-cold water heated 180°, or made to boil, with 1 lb. of wood —	lbs. 13.92	lbs. 14.33	lbs. 17.59	lbs. 20.10	—
Boiling-hot water kept boiling one hour with 1 lb. of wood — —	—	—	—	lbs. 132.68	lbs. 145.44

This ſet of Experiments was made at the ſame time with the foregoing ſet, namely, on the 13th October 1794, and they were made in the order in which they are here regiſtered. In the laſt but one, (No. 20.) the Economy of Fuel in the proceſs of heating water was carried farther than in any other Experiment I have ever made.

In the following Experiments, which were made in a large Copper Boiler fitted up on my moſt improved principles, belonging to the kitchen of the Houſe of Induſtry, the Economy of Fuel was carried nearly as far.

This Boiler, which is circular, is 42½ Engliſh inches in diameter above; 42.17 inches in diameter below; and 18.54 inches deep. It weighs 78½ lbs. Avoirdupois; and contains, when quite full, 714 lbs. *Bavarian weight* (= 884 lbs. Avoirdupois, or 106 gallons) of water, at the temperature of 55°.

It is ſurrounded above by a wooden ring about two inches in thickneſs, into which it is fitted; and in this ring, in a groove about ¾ of an inch deep, is fitted a circular wooden flat cover; this cover is formed in three pieces, united by iron hinges; and one of theſe pieces being faſtened down by hooks to the Boiler, the other two are ſo contrived as to be folded back upon it occaſionally. From the upper ſurface of the part of the cover which is faſtened down on the Boiler, a tin tube two inches in diameter, furniſhed with a damper, is fixed, by which the ſteam is carried off into a narrow wooden tube, which conducts it through an opening in the roof of the houſe into the open air.

To prevent ſtill more effectually the eſcape of the heat through the wooden cover of the Boiler, the upper ſurface of it is protected from the cold atmoſphere by a thick circular blanket covered on both ſides by ſtrong canvas, which is occaſionally thrown over it.

Though the diameter of this Boiler below is more than 40 inches, the diameter of its fire-place (which is juſt under its center) is only 11 inches; but as the flame makes two complete turns under the bottom of the Boiler in a ſpiral canal, and one turn round it, the time required to heat it is not ſo great as, from the ſmallneſs of its fire-place, might have been expected.

It has ever been, and ſtill continues to be, the decided favourite of the cook-maids.

The wood uſed as Fuel in the following Experiment was pine moderately dried. The billets were ſix inches long, and from one to two inches in diameter.

The following Table ſhows the reſults of five Experiments that were made with this Boiler by myſelf, juſt after it was fitted up:

	Experim No. 22.	Experim. No. 23.	Experim. No. 24.	Experim. No. 25.	Experim. No. 26.
Quantity of water in the Boiler, in Bavarian pounds — — —	lbs. 508	lbs. 127	lbs. 254	lbs. 508	lbs. 508
Temperature of the water at the beginning of the Experiment —	48°	48°	96°	48°	48°
Time required to make the water boil — —	h. min. 2 4	min. 51	h. min. 1 15	h. min. 2 35	h. min. 3 1
Fuel employed to make the water boil — —	lbs. 24$\frac{1}{3}$	lbs. 8$\frac{1}{4}$	lbs. 12$\frac{3}{4}$	lbs. 25	lbs. 24
Time the water continued boiling — —	h. 3	—	—	h. 3	—
Fuel added to keep the water boiling — —	lbs. 6$\frac{12}{32}$	—	—	lbs. 4$\frac{1}{2}$	—
Precise Results of the Experiments with the heat generated in the combuſtion of 1 lb. of the Fuel.					
Ice-cold water heated 180°, or made to boil -	lbs. 18.87	lbs. 12.74	lbs. 12.69	lbs. 17.48	lbs. 19.01
Or boiling-hot water kept boiling one hour -	236.61	—	—	338.66	—

Without ſtopping to make any obſervations on the reſults of theſe Experiments, (though they afford matter for ſeveral of an intereſting nature,) I ſhall proceed to give a brief account of another ſet of Experiments, on a much larger ſcale, which were made in the Copper Boiler of a Brewery belonging to the Elector.

This Boiler, which is rectangular, is ten feet long, eight feet wide, and four feet deep, *Bavarian meaſure* *, and contains 8176 *Bavarian maaſſe*, or meaſures, equal to 1866 gallons wine meaſure. On examining this Boiler, I found its fire-place was conſtructed on very bad principles; and on inquiry reſpecting the quantity of fire-wood conſumed in it, I found the waſte of Fuel to be very great.

This Brewery is uſed for making ſmall *white* beer, (as from its pale colour it is called,) from malt made of wheat; and as it is worked all the year round, the expence of Fuel was very great, and the economy of it an object of conſiderable importance.

The quantity of fire-wood (pine) that had at an average been conſumed daily in this Brewery was rather more than four Bavarian *clafters*, or cords. On altering the fire-place of this Brewery, and putting a (wooden) cover to the Boiler, I reduced this expence to leſs than 1½ clafters.

In the new fire-place which I cauſed to be conſtructed for this Boiler, the cavity under the Boiler is divided into three flues, by thin brick walls which run in the direction of the length of the Boiler. The middle flue, which is twice as wide as one of the ſide flues, is occupied by the burning Fuel, and is furniſhed with a grate 20 inches wide, and 36 inches long; and the opening by which the Fuel is introduced into the fire-place is cloſed by two iron doors, placed one behind the other, at the diſtance of eight inches. The grate, which is placed at the hither end of the fire-place, is horizontal, and it is ſituated about twenty inches below the bottom of the Boiler. The air which ſerves to feed the Fire, is let in under the grate through a regiſter in the aſh-pit door.

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* 100 Bavarian inches are equal to 95¾ inches Engliſh meaſure.

When the double doors which cloſe the entrance into the fire-place are ſhut, the flame of the burning Fuel firſt riſes perpendicularly againſt the bottom of the Boiler; it then paſſes along to the farther end of the (middle) flue, which conſtitutes the fire-place, where it ſeparates, and returns in the two ſide flues; it then riſes up into two horizontal flues (one ſituated over the other) which go all round the Boiler; and having made the circuit of the Boiler, it goes off into ſeparate canals (furniſhed with dampers) into the chimney.

Though the Figures 17 and 18, Plate III. are not drawings from the fire-place I am now deſcribing, but of another which I ſhall ſoon have occaſion to deſcribe, yet an inſpection of theſe figures will be found uſeful in forming an idea of the principles on which the fire-place in queſtion was conſtructed, and on that account I ſhall occaſionally refer to them.

The burning Fuel being confined within a narrow compaſs,—being well ſupplied with freſh air,—and being ſurrounded on all ſides by thin walls of brick, (which are non-conductors,) the heat of the fire is moſt intenſe, and the combuſtion of the Fuel of courſe very complete. The flame, which is clear and vivid in the higheſt degree, and perfectly unmixed with ſmoke, runs rapidly along the bottom of the Boiler, (which forms the top of the flues,) and from the reſiſtance it meets with in its paſſage, from friction, and from the number of turns it is obliged to make, it is thrown into innumerable eddies and whirlpools, and really affords a moſt entertaining ſpectacle.

That I might be able to enjoy at my eaſe this amuſing ſight, I cauſed a glaſs window to be made in the front wall of the fire-place, through which I could look into the Fire when the fire-place doors were ſhut; and I was well paid for the trouble and the trifling expence I had in getting it executed.

Some may be tempted to ſmile at what they may think a childiſh invention; but there are many others, I am confident, and among theſe many grave philoſophers, who would have been very glad to have ſhared my amuſement.

The window of which I am ſpeaking is circular, and only ſix inches in diameter; but as the hole in the wall is conical, and much larger within than without, the field of this window (if I may uſe the expreſſion) is ſufficiently large to afford a good view of what paſſes in the fire-place.

This conical hole is repreſented in the Figures 18 and 21, by dotted lines. It is ſituated on the left hand of the entrance into the fire-place. Into the opening of the hole in the wall, on the outſide of it, is fixed a ſhort tube of copper, (about ſix inches in diameter, and four inches long,) and in this tube another ſhort *moveable* tube is fitted, one end of which is cloſed by the circular plate of glaſs which conſtitutes the window. As the wall of the fire-place in front is thick, this pane of glaſs is at a conſiderable diſtance from the burning Fuel, and as there is no draft through the hole in the wall, the glaſs does not grow very hot.

I have been the more particular in my deſcription of this little invention, as I think it may be uſeful: There are many caſes in which it would be very advantageous to know exactly what is going on in a cloſed fire-place; and this never can be known by opening the door; for the inſtant the door is opened, the cold air ruſhing with impetuoſity into the fire-place, deranges entirely the whole economy of the Fire: Beſides this, it is frequently very diſadvantageous to the proceſs which is going on, to open the door of a fire-place; and it is always attended with a certain loſs of heat, and conſequently ſhould as much as poſſible be avoided.

I intimated that the window I have been deſcribing afforded me amuſement;—it did ſtill more,—it afforded me much uſeful information;—it gave me an opportunity of *obſerving* the various internal motions into which flame may, by proper management of the machinery of a fire-place, be thrown; and of eſtimating, with ſome degree of preciſion, their different effects. In ſhort, it made me better acquainted with the ſubject which had ſo long engaged my attention—(Fire);—and with regard to *that* ſubject, nothing ſurely that is new can be unintereſting. But to return to the Brewery:—To the top of the Boiler was fitted a curb of oak timber: The four ſtrait beams of which this curb was conſtructed are each about 7 inches thick, and 15 inches wide; and the upper part of the Boiler is faſtened by large copper nails to the inſide of the ſquare frame formed by theſe four beams. From the top of this curb is raiſed a wooden building, like the roof of a houſe with a double ſlant or bevel, which ſerves as a cover to the Boiler. This building, the ſides of which are about three feet high inwards, and the top of which is covered in by a very flat roof, ſlanting on every ſide from the centre,—is conſtructed of a light frame-work of timber, (four-inch deal joiſts,) which is covered within as well as without with thin deal boards, which are rabbetted into each other at their edges, to render the cover which this little edifice forms for the Boiler as tight as poſſible.

From the top of this cover, an open wooden tube, (*m*. Fig. 17.) about 12 inches in diameter, riſes up perpendicularly, and going through the roof of the Brewhouſe, ends in the open air. This tube, which is furniſhed with a wooden damper, is intended to carry off the ſteam.

On the ſide of this cover next the maſhing-tub, as alſo on that oppoſite to it, by which the wort runs off into the coolers, there are large folding wooden doors, (*i* and *k*, Fig. 17.) which are occaſionally lifted up by means of ropes which paſs over pullies faſtened to the ceiling of the Brewhouſe.

There are likewiſe two glaſs windows (ſee Fig. 17.) in two oppoſite ſides of the cover, through which, as ſoon as in conſequence of the boiling of the liquid the ſteam becomes tranſparent and *inviſible*, (which happens in a very few minutes after the liquid has began to boil,) the contents of the Boiler may be diſtinctly ſeen and examined.

Whenever there is occaſion during the boiling to open either a door or a window of the cover, it is neceſſary to begin by opening the damper of the ſteam-chimney, otherwiſe the hot ſteam, ruſhing out with violence, would expoſe the by-ſtanders to the danger of being ſcalded; but when the damper of the ſteam-chimney is open, no ſteam comes into the Brewhouſe, though a door or window of the cover be wide open.

Another ſimilar precaution is ſometimes neceſſary in opening the door of the fire-place, which it may be uſeful to mention.—When the dampers in the canals by which the ſmoke goes off into the chimney are nearly cloſed, (which muſt frequently be done to confine and economiſe the heat,) if, without altering the damper, or the regiſter in the aſh-pit door, the fire-place door be ſuddenly opened, it will frequently happen that ſmoke, and ſometimes flame, will ruſh out of the fire-place by this paſſage. This accident may be eaſily and effectually prevented, either by opening the damper, or by cloſing the regiſter of the aſh-pit door, the moment before the fire-place door is opened.—This precaution ſhould be attended to in all fire-places of all dimenſions, conſtructed on the principles I have recommended.

To economiſe the time and the *patience* of my reader as far as it is poſſible, without ſuppreſſing any thing eſſential relating to the ſubject under conſideration, I ſhall give him, in a very ſmall compaſs, the general reſults of a ſet of Experiments which coſt me more labour (or at leaſt more *time*) than it would coſt him to read all the Eſſays I have ever written. I believe I am ſometimes too prolix for the taſte of the age,—but it ſhould be remembered that the ſubjects I have undertaken to inveſtigate are by no means indifferent to me;—that I conceive them to be intimately connected with the comforts and enjoyments of mankind;—and that a habit of revolving them in my mind, and reflecting on their extenſive uſefulneſs, has awakened my enthuſiaſm, and rendered it quite impoſſible for me to treat them with cold indifference, however indifferent or tireſome they may appear to thoſe who have not been accuſtomed to view them in the ſame light.

I have already given an account, in all its various details, of one Experiment which was made, (on the 15th of April 1795,) with the Boiler we have juſt been deſcribing (ſee page 78). I ſhall now recapitulate the general reſults of that Experiment, and compare them with the mean reſults of two other like Experiments made with the ſame Boiler.

	Experiment No. 27.	Experiment No. 28.
Quantity of water in the Boiler -	12,508 lbs.	12,508 lbs.
Temperature of the water in the Boiler at the beginning of the Experiment - - - - - -	60°	58°
Time required to make the water boil - - - - - - - - - -	3 h. 40 min.	3 h. 48 min.
Fuel employed to make the water boil - - - - - - - - - -	800 lbs.	825 lbs.
Time the water continued boiling - - - - - - - - - -	2 h. 43 min.	—
Fuel added to keep the water boiling - - - - - - - -	100 lbs.	—
Kind of Fuel uſed - - - -	Pine-wood	Pine-wood
Precise Results of the Experiments.		
Quantity of *ice-cold water* which might be heated 180°, or made to boil, with the heat generated in the combuſtion of 1 *lb. of the Fuel* - - - - - -	12.06 lbs.	12.70 lbs.
Time in which, according to the reſult of the Experiment, *ice-cold water* might (at Munich) *be made to boil* with the given proportion of Fuel - - - -	4 h. 20 min.	4 h. 20 min.
Quantity of *boiling-hot water kept boiling one hour* with the heat generated in the combuſtion of 1 lb. of the Fuel -	339.80 lbs.	—

On comparing the reſults of theſe Experiments with thoſe made in the Boilers of the kitchens of the Houſe of Induſtry and Military Academy, I was led to imagine that either the Boiler, or the fire-place of the Brewery, or both, were capable of great improvement; for in ſome of the Experiments with theſe ſmall kitchen Boilers, the Economy of Fuel had been carried ſo far, that with the heat generated in the combuſtion of 1 lb. of pine-wood, it appeared that 20 lbs. of ice-cold water might have been made to boil;—but here, though the machinery was on a ſcale ſo much larger, (and I had concluded, too raſhly indeed, as will be ſhown hereafter, that the larger the Boiler the greater is of courſe the Economy of Fuel,)—the reſults of theſe Experiments indicated, that not quite 13 lbs. of ice-cold water could have been made to boil with the heat furniſhed in the combuſtion of 1 lb. of the wood.

The Experiments, No. 22, No. 25, and No. 26, which were made with the largeſt of my kitchen Boilers, had, it is true, afforded grounds to ſuſpect that, beyond certain limits, an increaſe of ſize in a Boiler does not tend to diminiſh the expence of Fuel in the proceſs of heating water; yet, as all my other Experiments had tended to confirm me in the opinion I had, at an early period, imbibed on that ſubject, I was diſpoſed to ſuſpect any other cauſe than the true one of having been inſtrumental in producing the unexpected appearances I obſerved.

I was much diſappointed, I confeſs, at finding that the Brewhouſe Boiler, notwithſtanding all the pains I had taken to fit up its fire-place in the moſt perfect manner, and notwithſtanding its enormous dimenſions, when compared with the Boilers I had hitherto uſed in my Experiments, ſo far from anſwering my expectations, actually required conſiderably more Fuel, in proportion to its contents, than another Boiler fitted up on the ſame principles, which was not *one fiftieth* part of its ſize.

This unexpected reſult puzzled me;—and I muſt own that it vexed me, though I ought perhaps to be aſhamed of my weakneſs;—but it did not diſcourage me. Finding on examining the Boiler, that its bottom was very thick, compared with the thickneſs of the ſheet copper of which my kitchen Boilers were conſtructed, it occurred to me that poſſibly *that* might be the cauſe, or at leaſt *one of the cauſes*, which had made the conſumption of Fuel ſo much greater than I expected; and as there was another Brewhouſe in the neighbourhood belonging to the Elector, which, luckily for me, ſtood in need of a new Boiler, I availed myſelf of that opportunity to make an Experiment, which not only decided the point in queſtion, but alſo eſtabliſhed a new fact with regard to heat, which I conceive to be of conſiderable importance.

Having obtained the Elector's permiſſion to arrange the ſecond Brewhouſe as I ſhould think beſt, I determined to ſpare no pains to render it as perfect as poſſible in all reſpects, and particularly in every thing relating to the Economy of Fuel. As in brewing, in the manner that buſineſs is carried on in Bavaria, where the whole proceſs, in as far as Fire is employed in it, is begun and finiſhed in the courſe of a day, *the ſaving of time*, in heating the water and boiling the wort, is an object of almoſt as much importance as that of economizing Fuel, and conſequently demanded particular attention.

The means I uſed for the attainment of both theſe objects will be evident from the following deſcription of the Boiler and its fire-place, which I cauſed to be conſtructed, and which are repreſented in all their details in the Plates III, IV, and V.

This Boiler is 12 (Bavarian) feet long, 10 feet wide, and only 2 feet deep. The ſheet copper of which it is made is uncommonly thin for a Boiler of ſuch large dimenſions, being at a medium leſs than *one-tenth* of an Engliſh inch in thickneſs. This Boiler, when finiſhed, weighed no more than 674 lbs. Bavarian weight, equal to 834¾ lbs. Avoirdupois, excluſive of 64 lbs. of copper nails uſed in rivetting the ſheets of copper together.

The top of the Boiler is ſurrounded by a ſtrong curb (*a*, *b*, Fig. 17.) of oak timber, to which it is attached by ſtrong copper nails, and over the Boiler is built a roof, or ſtanding cover, (ſee Fig. 17.) ſimilar in all reſpect to that already deſcribed. The bottom of the Boiler is flat, and repoſes horizontally on the top of the thin brick walls by which the fire-place is divided into flues. (See Fig. 18.)— Theſe flues do not run in the direction of the length of the Boiler, but from one ſide of it to the other;—conſequently the door of the fire-place is in the middle of one ſide of the Boiler.

The ſheets of copper, of which the bottom of the Boiler was conſtructed, run in the direction of the flues; and they are juſt ſo wide that their ſeams or joinings (where they are united to each other by their ſides) repoſe on the walls of the flues, except only in the middle flue, which, being about twice as wide as the others, one ſeam was neceſſarily left unſupported, at leaſt a conſiderable part of its length.—The ſheets of copper uſed in conſtructing this part of the bottom of the Boiler are rather thicker and ſtronger than the reſt: They are juſt 0.118 of an Engliſh inch in thickneſs.

The Fire is made under this Boiler in the middle flue, which, as I have juſt obſerved, is a little more than twice as wide as one of the other flues. There are *five* flues under the Boiler; namely, one in the middle 44 inches wide, above, in the clear, (which conſtitutes the fire-place,)—and *two* on each ſide of it, in which the flame circulates; one 20 inches wide, and the other 19 inches wide.

The ſide flues are each 14½ inches deep;—but as the walls which ſeparate them are much thicker below than above, where the bottom of the Boiler repoſes on them, the width of theſe flues below is only 13 inches.—The walls of theſe flues are ſhown by dotted lines in Fig. 17.

The walls which ſeparate the flues do not run quite from one ſide of the Boiler to the other; an opening being left at one end of each of them equal to the width of one of the narrow flues for the paſſage of the flame from one flue into another, without its going from under the Boiler.

The Fire being made (on a circular grate) in the middle flue (ſee Fig. 18.), the flame paſſes on in this flue to its farther end, and then, dividing to the right and left, comes forward in the two adjoining ſide-flues. Having arrived at the wall which ſupports the front of the Boiler, it turns again to the right and left; and, entering the two outſide flues, returns in them to the back of the Boiler. Here it went out (before the fire-place was altered) at two openings left for that purpoſe in the wall which ſupports the back part of the Boiler, and the two currents of flame uniting, entered a canal 7 inches wide, and 16 inches high, which goes all round the outſide of the Boiler. (See Fig. 20.) Having made the circuit of the Boiler, it went off by a canal (furniſhed with a damper) into the chimney.

From this deſcription of the fire-place, it appears that the flame and ſmoke generated in the combuſtion of the Fuel in paſſing through thoſe different flues, made a circuit of above 70 feet, in contact with the ſurface of the Boiler, before they were permitted to eſcape into the chimney. This I thought muſt be ſufficient to give theſe hot fluids an opportunity of communicating to the Boiler all the heat they could part with, notwithſtanding the difficulties which attend their getting rid of it: And I concluded that the communication of their heat to the Boiler would be much facilitated and expedited by the various eddies and whirlpools produced in the flame in conſequence of the number of abrupt turns and changes of direction it was obliged to make in paſſing under and round the Boiler.

As the Experiments which have been made with this Boiler were conducted throughout with the utmoſt care and attention, and as their reſults are both curious and important in ſeveral reſpects, I have thought them deſerving of being made known to the Public in all their details.

An Account of three Experiments made at Munich the 10th October 1796, with the new Boiler in the Brewery called *Neuheuſel*, belonging to HIS MOST SERENE HIGHNESS the ELECTOR.—The weather being fair: The barometer ſtanding at 28 Engliſh inches, and Fahrenheit's thermometer at 36°.

Dimenſions of the Boiler, in Engliſh meaſure, as found by actual meaſurement.	Length	11 feet	6.02 inches,
	Width	9 —	7.723 ——
	Depth	2 —	0.205 ——

Contents of the Boiler, when quite full to the brim, 14,163 lbs. *Bavarian weight* of water, at the temperature of 55°, equal to 17,540 lbs. Avoirdupois, or 2099 wine gallons.

The Boiler actually contained of water, in the beginning of each of the two following Experiments, - - - *in Bavarian weight,* ——8120 lbs. equal to 10,056 lbs. Avoirdupois, or nearly 1204 wine gallons.

The wood uſed in this and the following Experiments was *Pine,* which had been moderately ſeaſoned, and the billets were 3 feet 4¼ inches, Engliſh meaſure, in length.

FIRST EXPERIMENT WITH THE NEW BOILER.

Experiment, No. 29.

Time.			Fire-wood put into the Fire-place.		Temperature of the water in the Boiler.
Hours.	Min.		Number of Billets.	Quantity in weight. lbs.	In degrees of Fahrenheit's Therm.
11	31	A. M.	10	50	50°
—	46	—	15	25	54
12	0	—	5	25	64
—	10	P. M.	5	25	67
—	36	—	—	—	85
—	40	—	4	25	—
—	53	—	5	25	96
1	12	—	7	25	105
—	21	—	10	50	110
—	46	—	10	50	129
—	58	—	40	50	—
2	17	—	46	50	156
—	29	—	—	—	164
—	34	—	10	50	—
—	41	—	—	—	173
—	49	—	—	—	180
—	58	—	40	50	185
3	15	—	12	50	197
—	26	—	20	25	205
3	35	—	—	—	the water boiled.

Time employed, } 4 h. 4 min. Wood conſumed, 575 lbs.

The boiling water being let off, and it being replaced immediately with cold water, the Experiment was repeated as follows :

Experiment, No. 30.

Time.			Quantity of Fire-wood put into the Fire place.		Temperature of the water in the Boiler.
Hours.	Min.		Number of Billets.	Quantity in weight. lbs.	In degrees of Fahrenheit's Therm.
4	41	P. M.	40	50	60°
—	50	—	40	50	72
5	4	—	10	50	86
—	16	—	10	50	99½
—	29	—	10	50	114
—	42	—	10	50	126
—	56	—	40	50	142
6	10	—	40	50	157
—	24	—	40	50	—
—	28	—	—	—	172
—	40	—	40	50	—
—	42½	—	—	—	185½
—	53	—	40	50	—
—	55	—	—	—	198
7	2	—	—	—	205
7	7	—	—	—	the water boiled.

Time employed, } 2 h. 26 min. Wood conſumed, 550 lbs

This boiling water being let off, the Boiler was again filled (immediately) with cold water ; and in this third Experiment the quantity of water was increaſed to 11,368 lbs. *Bavarian weight*,—equal to 14,078 lbs. Avoirdupois, or 1685 wine gallons.

The reſults of this Experiment were as follows ;

Experiment, No. 31.

Time.			Quantity of Fire-wood put into the Fire-place.		Temperature of the water in the Boiler.
Hours.	Min.		Number of Billets.	Quantity in weight. lbs.	In degrees of Fahrenheit's Therm.
8	51	P. M.	80	100	65½°
9	7	—	40	50	79°
—	21	—	40	50	90
—	44	—	40	50	107
—	57	—	40	50	118
10	14	—	40	50	130
—	28	—	40	50	140
—	45	—	40	50	155
11	—	—	40	50	165
—	15	—	40	50	175
—	30	—	40	50	182
—	45	—	40	50	200
11	58	—	—	—	the water boiled.

Time employed, } 3 h. 7 min. Wood conſumed, 650 lbs.

The following Table will ſhow the reſults of theſe three Experiments in a clear and ſatisfactory manner:

	Experiment No. 29.	Experiment No. 30.	Experiment No. 31.
Quantity of water in the Boiler at the beginning of the Experiment, in *Bavarian pounds* - - - -	8120 lbs.	8120 lbs.	11,368 lbs.
Temperature of the water at the beginning of the Experiment -	50°	60°	65½°
Time employed in making the water boil -	4 h. 4 min.	2 h. 26 min.	3 h. 7 min.
Fuel (Pine wood) conſumed in making the water boil, in *Bavarian pounds* - - - -	575 lbs.	550 lbs.	650 lbs.
Preciſe Reſults of the Experiments.			
Quantity of ice-cold water which might have been heated 180 degrees, or made to boil with the heat generated in the combuſtion of 1 lb. of the Fuel -	12.54 lbs.	12.28 lbs.	14.59 lbs.
Time in which, according to the reſult of the Experiment, ice-cold water might be made to boil at Munich with the given proportion of Fuel - - - - -	4 h. 31 min.	2 h. 59 min.	3 h. 35 min.

I was ſurpriſed, when I compared the reſults of theſe Experiments with thoſe made in the other

Brewhouſe, to find how little in appearance I had gained by the alterations I had introduced; on a more careful examination of the matter, however, I found that I had gained much more than I at firſt imagined, both in reſpect to the Economy of Fuel, and to that of Time. The amount of theſe advantages will appear from the following compariſon of the mean reſult of theſe two ſets of Experiments:

	Preciſe Reſults of the foregoing Experiments.		
	Quantity of ice-cold water made to boil with 1 lb. of the Fuel.	Time required to make ice-cold water boil, according to the reſult of the given Experiment.	
Firſt Set.	lbs.	hrs.	min.
In the Experiment No. 27. —	12.06	4	20
In the Experiment No. 28, —	12.70	4	20
Sum —	24.77	8	40
Means —	12.385	4	20
Second Set.			
In the Experiment No. 29. —	12.54	4	31
In the Experiment No. 30. —	12.28	2	59
Sum —	24.82	7	30
Means —	12.41	3	45

The mean reſults of theſe two ſets of Experiments differ very little from each other in appearance; and from this circumſtance I ſhall prove, that the new Boiler is better adapted for ſaving Fuel than the old.

By comparing the reſults of the Experiments made with the ſame Boiler, but with different quantities of water, we ſhall conſtantly find that the expence of Fuel was *leſs* in proportion as the quantity of water was *greater*. In the Experiment No. 23, when 127 lbs. of water were uſed, the reſult of the Experiment indicated that no more than 12.74 lbs. of ice-cold water could be made to boil with the heat generated in the combuſtion of 1 lb. of the Fuel uſed; but in the Experiment No. 26, made with the ſame Boiler, but when 4 times as much water was uſed, or 508 lbs. it appeared from the reſult of the Experiment, that 19.01 lbs. of ice-cold water might be made to boil with 1 lb. of the Fuel.

Now, in the firſt ſet of the Experiments we are comparing, as the quantity of water uſed (12,508 lbs.) was much greater than that uſed in the ſecond ſet (8120 lbs.), it is evident, that if the conſtruction of the machinery and the Management of the Fire had been equally perfect in the two caſes, the Economy of Fuel would have been greateſt where the largeſt quantity of water was uſed;—that is to ſay, in the firſt ſet of Experiments;—but, as that was not the caſe, it is certain that the Boiler uſed in the ſecond ſet is better adapted to economize Fuel than that uſed in the firſt.

But we need not go ſo far to ſearch for proofs of that fact. The reſult of the Experiment No. 31

is alone ſufficient to put the matter beyond doubt. In this Experiment, in which the quantity of water (though ſtill conſiderably ſhort of that uſed in the former ſet of Experiments) was augmented from 8120 lbs. to 11,368 lbs. the ſaving of Fuel was ſo much increaſed as to ſhow in a deciſive manner the ſuperiority of the new Boiler.

The Preciſe Reſults	Quantity of ice-cold water made to boil with 1 lb. of the Fuel.	Time required to make ice-cold water boil, according to the reſult of the Experiment.	
	lbs.	hrs.	min.
Of this Experiment (No. 31.) were as follows, — — —	14.59	3	37
In the Experiments No. 27 and No. 28, they were, at a medium,	12.385	4	20

The difference in the expence of Fuel in theſe Experiments with theſe two Boilers is by no means inconſiderable; it amounts to above 14 *per cent.* and would have amounted to more, if more time had been allowed for heating the water in the Experiment with the new Boiler; for it is eaſy to ſhow—(what indeed was clearly indicated by all the Experiments)—that, in cauſing liquids to boil, the quantity of Fuel will be leſs in proportion as the time employed in that proceſs is long; or, which is the ſame,—as the Fire is ſmaller: And the ſaving of Fuel ariſing from any given prolongation of the proceſs, will be the greater as the fire-place is more perfect, and as the means uſed for confining the heat are more effectual.

Though the general reſults of theſe two ſets of Experiments afforded abundant reaſon to conclude that the alterations I had introduced in arranging the new Boiler were real improvements; yet, when I compared the quantity of Fuel conſumed in the Experiments with this new Boiler, with the much ſmaller quantities, in proportion to the quantity of water, which were employed in ſome of my former Experiments with kitchen Boilers, I was for ſome time quite at a loſs to account for this difference. In all my Experiments with Boilers of different ſizes, from the ſmalleſt ſaucepan up to the largeſt kitchen Boilers, I had invariably found that the *larger* the quantity of water was which was heated, the *leſs*, in proportion, was the quantity of Fuel neceſſary to be employed in that proceſs; and ſo entirely had that prejudice taken poſſeſſion of my mind, that when the ſtrongeſt reaſons for doubt preſented themſelves, they were overlooked; and it was not till I had ſearched in vain on every ſide to diſcover ſome other cauſe to which I could attribute the unexpected appearance that embarraſſed me, that I was induced,—I may ſay forced,—to abandon my former opinion, and to be convinced that what I had too haſtily conſidered as a general law, does not in fact obtain but within narrow limits;—that although, in heating *certain qualities* of liquids, there is an advantage in point of the Economy of Fuel in performing the proceſs on a larger ſcale, in preference to a ſmaller one; yet, when the liquid to be heated amounts to a certain quantity, this advantage ceaſes; and if it exceeds that quantity, it is attended with an expence of Fuel proportionally greater than when the quantity is leſs.

What the ſize of a Boiler muſt be, in order that the ſaving of Fuel may be a *maximum*, I do not pretend to have determined. I think however that there are ſome reaſons for ſuſpecting that it would not be larger than ſome of the kitchen Boilers uſed in my Experiments. But I recollect to have promiſed my Reader, that I would not give him my opinion, without laying before him at the ſame time the grounds of thoſe opinions.—In the preſent caſe they are as follows:

In an Experiment of which I have already given an account (No. 3.), $7\frac{15}{16}$ lbs. of water, at the temperature of 58°, were made to boil in a ſauce-pan fitted up in my beſt manner, in a cloſed fire-place; and the wood conſumed was 1 lb. This gives for the *preciſe reſult* of the Experiment, 6.68 lbs. of ice-cold water made to boil with 1 lb. of the Fuel.

In another Experiment (No. 12.) made with one of the ſmall Boilers belonging to the kitchen of the Military Academy, fitted up on the ſame principles, 43.63 lbs. of water, at the temperature of 60°, were made to boil with 3 lbs. of wood. This gives 11.93 lbs. of ice-cold water made to boil with 1 lb. of the Fuel.

Again, in the Experiment No. 20, which was made with a larger Boiler belonging to the ſame kitchen, and fitted up in the ſame manner, 187 lbs. of water, (equal to about 28 gallons,) at the temperature of 55°, were made to boil with the combuſtion of 8 lbs. of fire-wood. This gives 20.10 lbs. of ice-cold water made to boil with 1 lb. of the wood;—and farther than this I have not been able to puſh the Economy of Fuel.

In the Experiment No. 26. a Boiler was uſed, which had been conſtructed with the expreſs view to ſee how far it was poſſible to carry the Economy of Fuel in culinary proceſſes; and it was fitted up with the utmoſt care, and on the moſt approved principles. As I thought at that time that a large-ſized Boiler was eſſential to the economizing of Fuel, this Boiler was made to contain 106 gallons. In the Experiment in queſtion it actually contained 508 Bavarian pounds of water, (or about 63 gallons,) at the temperature of 48°; and to make this water boil, 24 lbs. of wood were conſumed. This gives 19.01 lbs. of ice-cold water made to boil with 1 lb. of Fuel. Hence it appears that the expence of Fuel was greater in this Experiment than in that laſt-mentioned.

Again, in the Experiment No. 31. when no leſs than 11,368 lbs or 1685 gallons, of water were heated and made to boil in the new Brew-houſe Boiler; the wood conſumed amounted to 650 lbs. which (as the temperature of the water at the beginning of the Experiment was $65\frac{1}{2}$°) gives for the *preciſe reſult* of the Experiment, 14.59 lbs. of ice-cold water made to boil with the heat generated in the combuſtion of 1 lb. of the Fuel.

As the relative quantities of Fuel expended in the Experiments are inverſely as the numbers expreſſing the quantities of ice-cold water, which, from the reſult of each Experiment, it appears might have been heated 180 degrees, or made to boil, under the mean preſſure of the atmoſphere at the level of the ſea, with the heat generated in the combuſtion of 1 lb. of the Fuel; it is evident that theſe numbers meaſure very accurately the different degrees to which the Economy of Fuel was carried in the different Experiments. The Economy of Fuel in heating liquids *depending on the quantity of the liquid*, as ſhown by the foregoing Experiments, may therefore be expreſſed ſhortly in the following manner:

	Quantity of water heated in the Experiment, *in Bavarian* lbs.	Degrees to which the Economy of the Fuel was carried.
	lbs.	lbs.
In the Experiment No. 3,	7.93	6.68
No. 12,	43.63	11.93
No. 16,	187	20.10
No. 26,	508	19.01
No. 31,	11,368	14.59

Before I take my leave of this ſubject I would juſt remark, that the cauſe of the appearances obſerved in the Experiments may, I think, be traced to that property of flame from which it has been denominated a non-conductor of heat:—For if the different particles of flame give off their heat only to bodies with which they actually come into contact, the quantity of heat given off by it will be,—*not as its volume*, (and conſequently not as the quantity of Fuel conſumed,) but rather *as its ſurface*. And as the ſurface of the flame, when fire-places are ſimilar, is proportionally greater in ſmall than in large fire-places;—the ſurfaces of ſimilar bodies being as the *ſquares* of their correſponding ſides, while their volumes are as the *cubes* of thoſe ſides;—it is evident that, on that account, leſs heat in proportion to the quantity generated in the combuſtion of the Fuel ought to be communicated to the Boiler, when the fire-place and Boiler are large, than when the proceſs is carried on upon a ſmaller ſcale.

There are, however, ſeveral other circumſtances to be taken into the account in determining the effects *of ſize* in the machinery neceſſary for boiling liquids; and one of them, which has great influence, is the heat abſorbed by the maſonry of the fire-place. This loſs will moſt undoubtedly be the ſmaller, as the fire-place is larger; but to determine the exact point when, the ſaving on the one hand being juſt counterbalanced by the loſs on the other, any augmentation or diminution of ſize in the machinery would be attended with a poſitive loſs of heat, is not eaſy to be aſcertained. Provided however that proper attention be paid to the *Management of the Fire*, and that as much heat as poſſible be generated in the combuſtion of the Fuel —(which may always be done in the largeſt fire-place as well, if not better, than in ſmaller ones); as that part of the heat which goes off in the ſmoke is indubitably loſt, a thermometer placed in the chimney would indicate, with a conſiderable degree of preciſion, the perfections or imperfections of the fire-place.

It is well known that the ſmoke which riſes from the chimnies of the cloſed fire-places of very large Boilers is much hotter than that which eſcapes from ſmaller fire-places; and I am ſurpriſed that this fact, which has long been known to me, ſhould not have led me to ſuſpect that the waſte of Fuel was proportionally greater in theſe large fire-places than in ſmaller ones.

Beſides the Experiments of which I have given an account, ſeveral others were made with the new Brewhouſe Boiler; and, among others, four Experiments were made on four ſucceeding days, in brewing Beer; and it was found that conſiderably leſs Fuel was expended in theſe trials, than was neceſſary in brewing the ſame quantity of beer in the other Brewhouſe, in which I firſt introduced my improvements. But though the alteration of form, diminution of the thickneſs of the metal, &c. which I had introduced in conſtructing the new Boiler, and alſo in the manner of fitting it up, had produced a conſiderable ſaving of Fuel, yet it was not accompanied by a proportional ſaving of time. I had flattered myſelf that by making the Boiler *very thin* and *very ſhallow*, I ſhould bring its contents to boil in *a very ſhort time;* but I did not conſider how much time is neceſſary for the combuſtion of the Fuel *neceſſary* for heating ſo large a quantity of water; otherwiſe my expectations on this head would have been leſs ſanguine. The quantity of heat generated in any given time being as the quantity of Fuel conſumed, it muſt depend in a great meaſure on the ſize of the fire-place; and when it is required to heat a large quantity of water, or of any liquid, in a very ſhort time, either the fire-place muſt be large, or (what in my opinion would be ſtill better) a number of ſeparate fire-places,—two or three, for inſtance,—muſt be made under the ſame Boiler. The Boiler ſhould be made wide and ſhallow, in order to admit of a great number of flues, in which the flame and ſmoke of the different Fires ſhould be made to circulate ſeparately *under its bottom.*

The combuſtion of the Fuel, and conſequently the generation and communication of the heat, may in the ſame fire-place be conſiderably accelerated by increaſing the draught (as it is called) of the Fire; which may be done by increaſing the height of the chimney, or by enlarging the canal leading to the chimney, and keeping the damper open, when that paſſage is too ſmall;—or by ſhortening the length of the flues.

The maſter brewer having expreſſed a wiſh that ſome contrivance might be uſed by which the water might be made to boil a little ſooner in the new Boiler, I made an alteration in its fire-place which completely anſwered that purpoſe.

But beſides the deſire I had to oblige the maſter brewer, (who only thought how he could contrive to finiſh as early as poſſible his day's work,) I had another, and much more important object in view. Having had reaſon to ſuſpect that flues which go round on the outſide of large Boilers do little more than prevent the eſcape of the heat by their ſides,—which, with infinitely leſs trouble and leſs expence, may be prevented by other means,—I was deſirous of finding out, by a deciſive Experiment, the real amount of the advantages gained by thoſe flues; or the ſaving of Fuel which they produce. And as I was confident that the ſuppreſſion of the flue which went round the new Boiler would increaſe the draught of the fire-place, and accelerate the combuſtion of the Fuel, I concluded that if my opinion was well founded with reſpect to the ſmallneſs of the advantages derived from theſe *ſide flues*, the increaſe of heat ariſing from the acceleration of the combuſtion occaſioned by the increaſed draught on cloſing them up would more than counterbalance the loſs of thoſe advantages, and the time employed in heating the water would be found to be actually leſs than it was before.

The reſults of the following Experiments ſhow how far my ſuſpicions were founded.

Experiment, No. 32.

The flue round the outſide of the new Brewhouſe Boiler having been cloſed up, and two canals (*a* and *b*, Fig. 21.) formed from the end of the two outſide flues of thoſe ſituated *under* the Boiler, by which two canals (which were both furniſhed with dampers) the ſmoke paſſed off from under the Boiler directly into the chimney; the Experiment No. 31. which was made with the ſame Boiler before the outſide flues were cloſed up, was now repeated with the utmoſt care, in order to aſcertain the effects which the cloſing up of thoſe flues would produce. The quantity of water in the Boiler, and its temperature at the beginning of the Experiment, were the ſame;—the wood uſed as Fuel was taken from the ſame parcel, and it was put into the fire-place in the *ſame quantities*, and at the *ſame intervals of time*;—in ſhort, every circumſtance was the ſame in the two Experiments, excepting only the alterations which had been made in the fire-place. As the length of the flues through which the flame and ſmoke was obliged to paſs to get into the chimney had been diminiſhed more than half, (or reduced from 70 to about 30 feet,) the ſtrength of the draught of the fire-place was much increaſed, as was evident not only from the increaſed violence of the combuſtion of the Fuel, which was very apparent, but alſo from another circumſtance, which I think it my duty to mention. Before the flue round the Boiler was cloſed, if too much Fuel was put into the fire-place at once, it not only did not burn with a clear flame, but frequently the ſmoke, and ſometimes the flame, came out of the fire-place door, even when the damper in the chimney was wide open; but after this flue was cloſed up, it was found to be hardly poſſible to overcharge the fire-place, and the Fuel always burned with the utmoſt vivacity.

I ought to inform my Reader, that though the entrance into the flue which went round the outſide of the Boiler was cloſed, and another and a ſhorter road opened for the flame and ſmoke to paſs off into the chimney, yet the *cavity* of the flue remained; and by means of openings (c. c. c. c. c. c. Fig. 21. Plate V.) about ſix inches ſquare in the brick-work which ſeparated this old road (which was now ſhut up) from the flues *under the Boiler*, the flame was permitted to paſs into this cavity, and to ſpread itſelf round the outſide of the Boiler. This contrivance (which I would recommend for all Boilers) not only prevents the eſcape of the heat out of the Boiler by its ſides, but contributes ſomething towards heating it; and as the openings in the ſides of the flues do not ſenſibly impede the motion of the flame, they can do no harm.

As the two Experiments, the reſults of which I am about to compare, were made with the greateſt care, and as they are on ſeveral accounts uncommonly intereſting, I ſhall place them in a conſpicuous point of view.

A COMPARATIVE VIEW of TWO EXPERIMENTS made with a new Brewhouſe Boiler.

The time is reckoned from the beginning of the Experiment, and was the ſame in both Experiments.

Quantity of water in the Boiler 11,368 *lbs. Bavarian weight.*

Time from the beginning of the Experiment.		Fuel put into the fire-place.		Heat of the water in the Boiler.	
		Number of billets.	Quantity in weight.	Experiment No. 31, (outſide flue open).	Experiment No. 32, (outſide flue cloſed).
hrs.	min.	No.	lbs.	degrees.	degrees.
—	—	80	100	65½	65½
0	16	40	50	79	82
0	30	40	50	90	94
0	53	40	50	107	110
1	6	40	50	118	122
1	23	40	50	130	135
1	37	40	50	140	147
1	54	40	50	155	160
2	9	40	50	165	171
2	24	40	50	175	182
2	39	40	50	182	191
2	54	40	50	200	—
2	59	—	—	—	boiled
3	7	—	—	boiled	—

Having found by comparing the reſults of theſe two Experiments, that I had loſt nothing in reſpect to the Economy of Fuel, by ſhutting up the outſide flue of my Boiler, I was now deſirous of aſcertaining how much I had gained in point of time, or how much the increaſed draught of the fire-place, in conſequence of its flues being ſhortened, enabled me to abridge the time employed in cauſing the contents of the Boiler to boil, in caſes in which it ſhould be advantageous to expedite that proceſs at the expence of a ſmall additional quantity of Fuel.

By the following Experiment, in which the combuſtion of the Fuel was made as rapid as poſſible by keeping the fire-place full of wood, and the regiſter in the aſh-pit door and the damper in the chimney conſtantly quite open, may be ſeen how far I ſucceeded in the attainment of that object.

Experiment No. 33.

The Boiler contained 11,368 lbs. Bavarian weight of water at the temperature of 47°. The Fuel uſed was pine-wood, moderately ſeaſoned, in billets three feet four inches long, and ſplit into ſmall pieces of about 1 lb. each, that it might burn the more rapidly.

This Experiment was made the 29th of November 1796, the barometer ſtanding at 26 inches 8.7 lines Paris meaſure, and Fahrenheit's thermometer at 33°.

Time.		Fuel put into the fire-place.	Temperature of the water in the copper.
hrs.	min	lbs.	degrees.
2	0	100	47
0	14	100	58
0	34	100	88
0	51	100	100
3	9	100	123
0	25	100	144
0	39	100	151
4	0	100	—
0	10	—	200
0	17	—	boiled
Time employed - 2	17	Wood conſumed - 800	

In the Experiment No. 32, the ſame quantity of water at the temperature of 65½°, was made to boil in 2 hours 59 minutes, with the conſumption of 625 lbs. of the ſame kind of wood. Had the water in this Experiment been as cold as it was in the Experiment No. 33, (namely at the temperature of 47°,) inſtead of 625 lbs., 705 lbs. of the Fuel would have been neceſſary; and the proceſs, inſtead of laſting 2 hours and 59 minutes, would have laſted 3 hours and 22 minutes.

Hence we may conclude, that to abridge 1 hour and 5 minutes of 3 hours and 22 minutes in the proceſs of boiling 11,368 lbs. of water, this cannot be done at a leſs additional expence of Fuel than that of 95 lbs. of pine-wood;—or, to abridge the time *one-third*, there muſt be an additional expence of about *one-eighth* more Fuel.

In ſome caſes it will be moſt profitable to ſave time, in others to economiſe Fuel;—and it will always be deſirable to be able to do either, as circumſtances may render moſt expedient.

From a compariſon of the quantities of Fuel conſumed, and conſequently of heat generated, in the ſame time, with the quantities of heat actually communicated to the water, in the Experiments No. 32 and No. 33, during this time, an idea may be formed of the great quantity of heat that may remain in flame and ſmoke after they have paſſed many feet in flues under the thin bottom of a Boiler containing cold water; and this ſhows with how much difficulty theſe hot vapours part with their heat, and how important it is to be acquainted with that fact in order to take meaſures with certainty for economiſing Fuel.

I have been the more particular in my account of theſe Experiments with large Boilers, as I believe no Experiments of the kind on ſo large a ſcale have been yet made; and as they were all conducted with care, their reſults have intrinſic value independent of the particular uſes to which I have applied them.

As in the countries where this Eſſay is likely to be moſt read, pit-coals are more frequently uſed as Fuel than wood, it will not only be ſatisfactory, but in many caſes may be really uſeful to my Reader to know the relative quantities of heat producible from coals and from wood; in order to be able to compare the reſults of Experiments in which coals are uſed as Fuel, with thoſe of which I have here given an account; or to determine the quantity of coals neceſſary in any proceſs which it is known may be performed with a given quantity of wood.

It was my intention to have made a ſet of Experiments on purpoſe to determine the relative quantities of heat producible from all the various kind of combuſtible bodies which are uſed as Fuel; and I made preparations for beginning them, but I have not yet been able to find leiſure to attend to the ſubject.

The moſt ſatisfactory account I have been able to procure reſpecting the matter in queſtion, is one for which I am indebted to my friend Mr. KIRWAN. By this account, which he tells me is founded on Experiments made by Mr. *Lavoiſier*, it appears, that equal quantities of water, under equal ſurfaces, may be evaporated, and conſequently equal heats produced,

By 403 lbs. of Coaks	or in meaſure	By 17 of Coaks
600 — of Pit-coal		10 of Pit-coal
600 — of Charcoal		40 of Charcoal
1089 — of Oak		33 of Oak.

I wiſh I were at liberty to tranſcribe the ingenious and intereſting obſervations which accompanied this eſtimate; but as they make part of a work which I underſtand is preparing for the Preſs, I dare not anticipate what Mr. KIRWAN will himſelf ſoon lay before the Public.

According to this eſtimate it appears that 1089 lbs. of oak produces as much heat in its combuſtion as 600 lbs. of pit-coal. Now, if we ſuppoſe that the pine-wood uſed in my Experiments is capable of producing as much heat *per pound* as oak,—and I have reaſon to think it does not afford leſs,—from the quantity of pine-wood uſed in any of my Experiments, it is eaſy to aſcertain how much coal would have been neceſſary to generate the ſame quantity of heat; for the weight of the coal which would be required is, to the weight of the wood actually conſumed, 600 to 1089.

In one of my Experiments (No. 31,)—11,368 lbs. of water, at the temperature of 65½°, were made to boil with 650 lbs. of pine-wood. As, when the Experiment was made, the mercury in the barometer ſtood at about 28 Engliſh inches, the temperature of the water when it boiled was only 209½°, conſequently its temperature was raiſed (209½—65½) 144 degrees. Had the water been boiled in London, or in any other place nearly on a level with the ſurface of the ſea, it muſt have been heated to 212° to have been made to boil,

conſe-

conſequently its temperature muſt have been raiſed 146½°; and to have done this, inſtead of 650 lbs. of wood, 661½ lbs. would have been required; (144° is to 146½ as 650 lb. to 661½ lbs.)

If pit-coal were uſed inſtead of wood, 363½ lbs. of that kind of Fuel would have been ſufficient;—for the quantities of different kinds of Fuel required to perform the ſame proceſs being inverſely as the quantities of heat which equal weights of the given kinds of Fuel are capable of generating, or directly as the quantities of the kind of Fuel in queſtion, which are required to produce the ſame heat, it is 1089 to 600, as 661½ lbs. of wood to 363½ lbs. of coal, ſuppoſing the foregoing eſtimate to be exact.

Whether it would be poſſible to cauſe ſo large a quantity of water, (1681 wine gallons,) at the given temperature, (65½°,) to boil, with this ſmall quantity of coal, I leave to thoſe who are converſant in Experiments of this kind to determine.

From the reſult of my 20th Experiment it appeared that 20$\frac{1}{10}$ lbs. of ice-cold water might be heated 180 degrees, or made to boil under the mean preſſure of the atmoſphere at the level of the ſurface of the ocean, with the heat generated in the combuſtion of 1 lb. of pine-wood. Computing from the reſult of this Experiment, and from the relative quantities of heat, producible from pine-wood, and from pit-coal, it appears that the heat generated in the combuſtion of 1 lb. of pit-coal, would make 36$\frac{3}{10}$ lbs. of ice-cold water boil.

Hence it appears that pit-coal ſhould heat 36 times its weight of water, from the freezing point to that of boiling;—and as it has been found by Experiments made with great care by Mr. WATT, that nearly $5\frac{1}{4}$ times as much heat as is ſufficient to heat any given quantity of ice-cold water to the boiling point, is required to reduce that ſame quantity of water, *already boiling-hot*, to ſteam; according to this eſtimation, the heat generated in the combuſtion of 1 lb. of coal ſhould be ſufficient to reduce very nearly 7 lbs. of boiling-hot water to ſteam.

How far theſe eſtimates agree with the Experiments that have been made with ſteam-engines, I know not; but there ſeems to be much reaſon to ſuſpect that the expence of Fuel, in working thoſe engines, is conſiderably greater than it ought to be, or than it would be, were the Boilers and Fire-places conſtructed on the beſt principles, and the Fire properly managed.

In attempts to improve, it is always very deſirable to know exactly what progreſs has been made;—to be able to meaſure the diſtance we have laid behind us in our advances; and alſo that which ſtill remains between us and the object in view. The ground which has been gone over is eaſily meaſured; but to eſtimate that which ſtill lies before us is frequently much more difficult.

The advances I have made in my attempts to improve fire-places, for the purpoſe of economiſing Fuel, may be eſtimated by the reſults of the

Experiments of which I have given an account in this Eſſay; but it would be ſatisfactory no doubt to know how much farther it is poſſible to puſh the Economy of Fuel.

In my 4th Experiment, $7\frac{15}{16}$ lbs. of water, at the temperature of 58°, were made to boil, at Munich, with 6 lbs. of wood. If, from the reſult of this Experiment, we compute the quantity of ice-cold water which, with the heat generated in the combuſtion of 1 lb. of the Fuel, might be heated 180 degrees, or made to boil, it will turn out to be only $1\frac{1}{7}$ lb. or more exactly 1.11 lb.

According to the reſult of the Experiment No. 20, it appeared, that no leſs than $20\frac{1}{10}$ lbs. of ice-cold water might have been made to boil with the heat generated in the combuſtion of 1 lb. of pine-wood.

It appears, therefore, that about *eighteen times* as much Fuel, in proportion to the quantity of water heated, was expended in the Experiment No. 4, as in that No. 20; and hence we may conclude with the utmoſt certainty, that of the heat generated, or which, with proper management, might have been generated in the combuſtion of the Fuel uſed in the 4th Experiment, leſs than $\frac{1}{18}$ part was employed in heating the water;—the remainder, amounting to more than $\frac{17}{18}$ of the whole quantity, being diſperſed and loſt.

I ventured to give it as my opinion in the beginning of this Eſſay, that "not leſs than *ſeven-eighths* "of the heat generated, or which, with proper ma-

" nagement, might be generated from the Fuel ac-
" tually conſumed, is carried up into the atmoſphere
" with the ſmoke, and totally loſt."—I will leave it to my Reader to judge whether this opinion was not founded on good and ſufficient grounds.

But though it be proved beyond the poſſibility of a doubt, that the proceſs of heating water was performed in the 20th Experiment with about $\frac{1}{18}$ part of the proportion of Fuel which was actually expended in the 4th Experiment, yet neither of theſe Experiments, nor any deductions that can be founded on their reſults, can give us any light with reſpect to the *real* loſs of heat, or how much leſs Fuel would be ſufficient were there no loſs whatever of heat. The Experiments ſhow that the loſs of heat muſt have been at leaſt *eighteen times* greater in one caſe than in the other; but they do not afford grounds to form even a probable conjecture reſpecting the amount of the loſs of heat in the Experiment in which the Economy of Fuel was carried the fartheſt, or the poſſibility of any farther improvements in the conſtruction of fireplaces. I ſhall, however, by availing myſelf of the labours of others, and comparing the reſults of their Experiments with mine, endeavour to throw ſome light on this abſtruſe ſubject.

Doctor Crawford found, by an Experiment contrived with much ingenuity, and which appears to have been executed with the utmoſt care, that the heat generated in the combuſtion of 30 grains of charcoal raiſed the temperature of 31 lbs. 7 oz. Troy = 181,920 grains, of water, $1\frac{71}{100}$ degrees of Fahrenheit's thermometer, *when none of the heat generated was ſuffered to eſcape.*

But if 30 grains of charcoal are neceſſary to raiſe the temperature of 181,920 grains of water $1\frac{71}{100}$ degrees, it would require 3157.9 grains of charcoal to raiſe the temperature of the ſame quantity of water 180 degrees, or from the point of freezing to that of boiling; for it is 1.71° to 30 grains, as 180° to 3157.9 grains. Conſequently the heat generated in the combuſtion of 1 lb. of charcoal would be ſufficient to heat 57.608 lbs. of ice-cold water 180 degrees, or to make it boil;—for 3157.9 grains of charcoal are to 181,920 grains of water as 1 lb. of charcoal to 57.608 lbs. of water.

From the reſults of Mr. LAVOISIER's Experiments, it appeared that the quantities of heat generated in the combuſtion of equal weights of charcoal and dry oak, are as 1089 to 600. Hence we may conclude, that equal quantities of heat are generated by 1 lb. of charcoal and 1.815 lbs. of oak; conſequently that the heat generated in the combuſtion of 1.815 lbs. of oak, would heat 57.608 lbs. of ice-cold water,—or 1 lb. of oak, 31.74 lbs. of ice-cold water 180 degrees, or cauſe it to boil;—*were no part of the heat generated in the combuſtion of Fuel loſt.*

If now we ſuppoſe the quantities of heat producible from equal weights of dry oak and of dry pine-wood to be equal,—(and there is reaſon to believe that this ſuppoſition cannot be far from the truth,) we can eſtimate the real loſs of heat in each of the two Experiments before mentioned, (No. 4 and No. 20,) as alſo in every other caſe in which the quantity of Fuel conſumed, and the effects produced by the heat, are known.

Thus, for inſtance, in the 20th Experiment, as the effects actually indicated that with *that part* of the heat generated in the combuſtion of 1 lb. of the Fuel which *entered the boiler*, $20\frac{1}{10}$ lbs. of ice-cold water might have been made to boil; as by the above eſtimate it appears that $31\frac{74}{100}$ lbs. of ice-cold water might be made to boil with *all* the heat generated in the combuſtion of 1 lb. of the Fuel—it is evident that about *one-third* of the heat generated was loſt; or $\frac{20.1}{31.74}$ of it was ſaved.

This loſs is certainly not greater than might reaſonably have been expected, eſpecially when we conſider all the various cauſes which conſpire in producing it; and I doubt whether the Economy of Fuel will ever be carried much farther.

In the Experiment No. 4, as the effects produced by the heat which entered the Boiler indicated that no more than 1.14 lb. of ice-cold water could have been made to boil with 1 lb. of the Fuel, it appears that in this Experiment only about $\frac{1}{28}$th part of the heat generated was ſaved.

In all the Experiments made on a very large ſcale, with Brewhouſe Boilers, rather more than *one-half* of the heat generated found its way up the chimney, and was loſt.

CHAP. VI.

A ſhort Account of a Number of Kitchens, public and private, and Fire-places for various Uſes, which have been conſtructed under the Direction of the Author, in different Places.—Of the Kitchen of the HOUSE *of* INDUSTRY *at* MUNICH—*Of that of the* MILITARY ACADEMY—*Of that of the* MILITARY MESS-HOUSE—*That of the* FARM-HOUSE, *and thoſe belonging to the* INN *in the* ENGLISH GARDEN *at* MUNICH.—*Of the Kitchens of the Hoſpitals of* LA PIETA *and* LA MISERICORDIA *at* VERONA.—*Of a ſmall Kitchen fitted up as a Model in the Houſe of* SIR JOHN SINCLAIR *Bart. in* LONDON.—*Of the Kitchen of the* FOUNDLING HOSPITAL *in* LONDON.—*Of a* MILITARY KITCHEN *for the Uſe of* TROOPS *in* CAMP.—*Of a* PORTABLE BOILER *for the Uſe of* TROOPS *on a* MARCH.—*Of a large* BOILER *fitted up as a Model for* BLEACHERS *at the* LINEN-HALL *in* DUBLIN.—*Of a Fire-place for* COOKING, *and at the ſame Time* WARMING A LARGE HALL; *and of a* PERPETUAL OVEN, *both fitted up in the* HOUSE *of* INDUSTRY *at* DUBLIN.—*Of the* KITCHEN—LAUNDRY—CHIMNEY FIRE-PLACES—COTTAGE FIRE-PLACE—*and Model of* *of a* LIME-KILN—*fitted up in* IRELAND *in the Houſe of the* DUBLIN SOCIETY.

MY wiſh to give the moſt complete information poſſible with regard to the *grounds* on which the improvements I propoſe are founded, has induced me to be very particular in my account of my Experiments, and of the concluſions and practical inferences I have thought myſelf authoriſed to draw from them; and as theſe inveſtigations have frequently led me into abſtruſe philoſophical diſquiſitions which might not perhaps be very intereſting to many of my readers, to whom a ſimple account of my Fire-places, with directions for conſtructing them, might be really uſeful; in order to accommodate readers of all deſcriptions, I have thought it beſt to divide my ſubject, and to reſerve what I have ſtill to ſay on the mechanical part of it,—the Conſtruction of Kitchen Fire-places,—for a ſeparate Eſſay. In the mean time, for the information of thoſe who may have opportunities of examining any of the Kitchens, or Fire-places, for other purpoſes, which have already been conſtructed on my principles, under my direction, I have annexed the following account of them, and of the particular merits and imperfections of each of them. This account, added to what has been ſaid in the foregoing Chapters of this Eſſay on the conſtruction of Fire-places, will, I flatter myſelf, be found ſufficient to convey the fulleſt information reſpecting the ſubject under conſideration, and enable thoſe, who may wiſh to adopt the propoſed improvements, to conſtruct Fire-places of all kinds on the principles recommended, without any farther aſſiſtance.

Thoſe who may not have leiſure to enter into theſe ſcientific inveſtigations, and who, notwithſtanding, may wiſh to imitate theſe inventions, will find all the information they can want in my next Eſſay.

An Account of the Kitchen of the HOUSE *of* INDUSTRY *at* MUNICH, *in its preſent State.*

THE large circular copper boiler (which is ſituated in a ſmall room adjoining to the great Kitchen) is fitted up in a very complete manner;—its (wooden) cover is cheap, ſimple, and durable, and anſwers perfectly well for confining the heat;—the ſteam-tube (or ſteam-chimney, as I have called it) is very uſeful, as it carries off all the ſteam generated in cooking, and keeps the air of the Kitchen dry and wholeſome.—To carry off the ſteam which riſes from the hot ſoup when it is ſerved up, there is a ſteam-chimney of wood, (furniſhed with a valve,) the opening of which is ſituated at the higheſt part of the Kitchen. To prevent the cold air from coming down by this paſſage into the Kitchen, its damper (which is opened and ſhut by a cord which goes over a pulley) is, in winter, kept conſtantly ſhut, except juſt when it is neceſſary to open it for a moment to let out the ſteam.

The only alteration I would make, were I to fit up this boiler again, would be to leave openings by which the flues might be cleaned occaſionally, without lifting the boiler out of its place.—This ſhould be done in the fire-places of all large boilers. This boiler, which is uſed every day, requires to have its flues cleaned, and its bottom and ſides ſcrubbed with a broom, to free them of ſoot, once in ſix weeks.

Over againſt this boiler is a machine for drying potatoes, which has been found to anſwer perfectly well the end for which it was contrived. Potatoes firſt moderately boiled, and then ſkinned and cut into thin ſlices, and dried in this machine, may be kept good for many years.

The eight iron boilers in the *great Kitchen* are fitted up on good principles; and the oven which is heated by the ſmoke from the fire-places of two of theſe boilers, which oven is deſtined for drying the wood for the uſe of this Kitchen, is deſerving of attention.

The wooden covers of theſe eight boilers, and the horizontal tubes, conſtructed of wood wound round with canvas and painted with oil colours, by which the ſteam is carried off, have been found to anſwer very well the purpoſes for which they were contrived.

The Kitchen of the Military Academy at MUNICH.

This Kitchen in its preſent ſtate is ſo perfect in all its parts, that I do not think it capable of any conſiderable improvement. The *roaſter*, which has been in daily uſe *ſeven years*, is ſtill in good condition, and bids fair to laſt *twenty years* longer.—It is large and roomy, and has been found to be extremely uſeful. Though the different parts of this Kitchen are not diſtributed with ſo much ſymmetry as could have been wiſhed, owing to local circumſtances, yet it is very complete in its various details, and all the various proceſſes of cookery are performed in it with little labour, and with a very ſmall expence indeed of Fuel. Two large boilers and three large ſaucepans, which are fitted up in a detached maſs of brick-work in a corner of the room, (on the right hand on going into it,) I can recommend as perfect models for imitation. In ſhort, I know of nothing which I could wiſh to alter in this Kitchen.—To ſay the truth, it has already undergone a ſufficient number of changes and alterations.

The Kitchen in the Military Hall or Officers' Meſs-Houſe in the Engliſh Garden at MUNICH.

This Kitchen is much leſs perfect in its details than that juſt mentioned.—It was built in the ſpring of the year 1790, and has ſince undergone only a few trifling alterations. It has three roaſters, which are made ſmall on purpoſe to ſerve as models for private families; and I have had the pleaſure to know that they have often been imitated.

The Kitchen in the Farm-Houſe in the Engliſh Garden.

This Kitchen is well contrived for the uſe for which is was deſigned, and I can recommend it as a very good model for the Kitchens of Farm-houſes, for families conſiſting of eighteen or twenty perſons. One of the boilers, which is deſtined for warming water for the uſe of the Kitchen and the ſtables, is in winter heated by the ſmoke of a German ſtove which is ſituated in an adjoining room, —that inhabited by the Overſeer of the farm.

The great Kitchen of the Inn in the Garden.

This Kitchen, which is adjoining to the Farm-houſe, is contrived almoſt for the ſole purpoſe of roaſting chickens before an open fire, a kind of food of which the Bavarians are extravagantly fond. It has three open fire-places, conſtructed on the principles recommended in my Eſſay on Chimney Fire-places, fronting different ſides of the Kitchen, and all opening into the ſame chimney, which chimney is built nearly in the middle of the room. This Kitchen was built before my roaſters were come into uſe.

The ſmall Kitchen belonging to the Inn.

This Kitchen has nothing belonging to it which deſerves attention, or which I would recommend for imitation. It was originally deſigned merely for making coffee, chocolate, &c.

A Kitchen which has lately been fitted up on my principles, in the new Hoſpital for the infirm and helpleſs Poor, which is ſituated on the height called the *Gaſteig*, on the ſide of the river oppoſite to the town of Munich, is much more intereſting, and is a good model for imitation.

The Kitchen of the Hoſpital of La Piéta at VERONA

Is peculiarly intereſting, on account of its convenient form and the perfect ſymmetry of its parts.

The maſs of brick-work in which the boilers are fixed occupies the middle of one ſide of a large high room, which is plaiſtered and white-waſhed, and neatly paved. The covers of the large boilers are lifted up by ropes which go over pullies fixed to the ceiling of the top of the room; but were I to build the Kitchen again, I ſhould ſubſtitute wooden covers with ſteam-chimnies inſtead of them, ſuch in all reſpects as that belonging to the large round copper boiler in the Kitchen of the Houſe of Induſtry at Munich. When the covers are ſo large that they cannot conveniently be lifted on and off with the hand, they ſhould, in my opinion, always be made of wood, and divided into parts, united by hinges. When they are deſigned for confining the ſteam *entirely*, they ſhould be made on a peculiar conſtruction, which will hereafter be deſcribed. The covers for ſmall boilers, and thoſe for ſauce-pans, ſhould always be of tin, and double.

The grates on which the fires are made under the boilers in the Kitchen of the Hoſpital of *La Piéta*, are circular; but they are not hollow, or diſhing, as that improvement did not occur to me till after that Kitchen was finiſhed. The ſpiral flues under the boilers are alſo wanting, and for the ſame reaſon. In all other reſpects this Kitchen is, I believe, quite perfect.

The Kitchen of the Hoſpital of La Miſericordia at VERONA

Is conſtructed on the ſame principles as that of *La Piéta*. The only difference between them is in the diſtribution of the boilers. That of *La Miſericordia* is built round two ſides of the room. In many caſes, this manner of diſpoſing of the boilers will be found more convenient than any other; but in all caſes where this method of placing them is preferred, care muſt be taken to place the largeſt boilers fartheſt from the chimney, and the ſmaller ones nearer to it, and in regular ſucceſſion as their ſizes diminiſh. This is neceſſary, in order that in the maſs of brick-work in which the boilers are fixed, there may be room behind the ſmaller boilers for the canals which carry off the ſmoke from the large ones into the chimney.

This circumſtance was attended to in conſtructing the ſmall Kitchen which I fitted up laſt ſpring in the houſe of Sir John Sinclair, Bart. Preſident of the Board of Agriculture, Whitehall, London. This Kitchen (which was intended to ſerve as a model, and is open to the public view at all hours) is by no means as perfect as I wiſhed it to be:— Having been built during my journey to Ireland, ſeveral miſtakes were made by the workmen I employed, who, though they have great merit in their different lines of buſineſs, had not *then* had ſufficient experience in conſtructing Kitchens on my principles, to be able to execute ſuch a job in my abſence without committing ſome faults. Thoſe which were moſt eſſential I corrected; but my ſtay in England after my return from Ireland was too ſhort, and my time too much taken up with other matters, to rebuild the Kitchen from the foundation; which I was very deſirous of doing, and which, with the permiſſion of the Proprietor, I ſhall certainly do when I come to England again. The greateſt fault of the Kitchen is the want of dampers to the canals by which the ſmoke is carried off from the cloſed fire-places of the boilers and ſaucepans into the chimney. Theſe dampers ſhould never be omitted in any fire-place, however ſmall. They are neceſſary even in fire-places for the ſmalleſt ſaucepans, and no large boiler ſhould on any account be without one. Some Experiments I have lately made (ſince my return to Bavaria) have ſhewed me how very neceſſary theſe dampers are; and I conſider it as my duty to the Public to loſe no time in recommending the general uſe of them. The flattering attention which has been paid by the Public to the various improvements I have taken the liberty to propoſe, not only demands my warmeſt gratitude, but lays me under an indiſpenſable obligation to exert myſelf to the utmoſt to deſerve their eſteem, and to merit the diſtinguiſhed marks of their confidence with which on ſo many occaſions I have been honoured.

But to return to the Kitchen in the houſe of Sir John Sinclair (the place where the meetings of the Board of Agriculture are held, and where of courſe there is a great concourſe of ingenious men from all parts of the kingdom,—of men zealous for the progreſs of uſeful improvements). As the room is very ſmall, it was not poſſible to do more in it than juſt to fit up a few ſmall boilers and ſaucepans, and one middling-ſized roaſter, ſuch as might ſerve for a ſmall family; which laſt is a machine ſo very uſeful that I cannot help flattering myſelf that it will ſoon come into general uſe. The ſaving of Fuel which it occaſions is almoſt incredible, and the meat roaſted in it is remarkably well-taſted and high-flavoured.

One of theſe roaſters, on a large ſcale, was put up, under my direction, in the Kitchen of the Foundling Hoſpital in London; and though I could not ſtay in England to ſee it finiſhed, I have had the ſatisfaction to learn, ſince my arrival at Munich, from my friend Mr. Bernard, (who is Treaſurer to the Hoſpital,) that it has anſwered even beyond his expectations. He informs me, that when 112 lbs. of beef are roaſted in it at once, the expence for Fuel amounts to no more than *four pence* ſterling; and this when the coals are reckoned at an uncommonly high price, namely, at 1 s. 4 d. the buſhel.

In the roaſter belonging to the Kitchen of the Military Academy at Munich, I cauſed 100 lbs. Bavarian weight (equal to 123.84 lbs. Avoirdupois) of veal, in *ſix large pieces*, to be roaſted at once, as an Experiment; the Fuel conſumed was 33 lbs. Bavarian weight of dry pine-wood, (equal to 40.86 lbs. Avoirdupois,) which (at 4½ florins the *clafter*, weighing 2967 lbs. Bavarian weight) coſt 3 creutzers, or about *one penny* ſterling.

This Experiment was made in the year 1792. Happening to mention the reſult of it in a large company in London, ſoon after my arrival there in the autumn of the year 1795, I had the mortification to perceive very plainly by the countenances of my hearers how dangerous it is to promulgate very extraordinary truths. I afterwards grew more cautious, and ſhould not now have ventured to publiſh this account, had not the reſults of Experiments equally ſurpriſing, which have been made with the roaſter in the Kitchen of the Foundling Hoſpital, been made known to the Public.

Not only the roaſter, but the boilers alſo which have been put up under my direction in the Kitchen of the FOUNDLING HOSPITAL, have been found to anſwer very well; and I am informed that ſeveral other great Hoſpitals are about to imitate them. As I left London before the Kitchen of the Foundling Hoſpital was entirely finiſhed, I do not know whether there are dampers to the canals by which the ſmoke goes off from the fire-places of the boilers, and from that of the roaſters, to the chimney. If there are not, I could wiſh they might ſtill be added; and I would ſtrongly recommend it to thoſe who may be engaged in conſtructing Kitchen fire-places on my principles, never to omit them.

Oval graters of caſt iron, in the form of a diſh, ſuch as I have deſcribed in the foregoing Chapters of this Eſſay, were tried in the Kitchen of the Foundling Hoſpital, but the heat was found to be ſo intenſe that they were ſoon melted and deſtroyed; and we were obliged to have recourſe to common flat grates, compoſed of ſtrong bars of caſt iron. Perhaps the heat generated in the combuſtion of pit-coal is ſo intenſe, when completely confined, (as it ought always to be in cloſed fire-places,) that it will not be poſſible, where coals are uſed as Fuel, to uſe the hollow diſhing grates I have introduced in the public Kitchens at Munich, and which have been deſcribed and recommended in this Eſſay.

Since my return to Bavaria, I have made ſeveral Experiments with grates compoſed of common bricks, placed edgewiſe, and I find that they anſwer for that uſe full as well, if not better, than iron bars. By making bricks *on purpoſe* for this uſe, of proper forms and dimenſions, and compoſed of the beſt clay mixed with broken crucibles beaten to a coarſe powder, Kitchen fire-places might be fitted up with them, which would be both cheap and durable, and as perfect in all other reſpects as any that could poſſibly be made, even were the moſt coſtly materials to be uſed in their conſtruction.

To diminiſh ſtill farther the expence attending the conſtruction of cloſed Kitchen fire-places deſigned for the uſe of poor families, the opening by which Fuel is introduced might be cloſed with a brick, or with a flat ſtone;—another brick, or ſtone, might be made to ſerve at the ſame time as a regiſter and a door to the aſh-pit, and a third as a damper to the chimney or canal for carrying off the ſmoke from the fire-place.

I lately had an opportunity of fitting up a Kitchen on theſe principles, in the conſtruction of which there was not a particle of iron uſed, or of any other metal, except for the boiler. On the approach of the French army under General Moreau in Auguſt laſt, the Bavarian troops being aſſembled at Munich (under my command) for the defence of the capital, the town was ſo full of ſoldiers,

diers, that ſeveral regiments were obliged to be quartered in public buildings, and encamped on the ramparts, where they had no conveniencies for cooking.—For the accommodation of a part of them, four large oblong ſquare boilers, compoſed of very thin ſheet coppers well tinned, were fitted up in a maſs of brick-work in the form of a croſs; each boiler with its ſeparate fire-place, communicating by double canals, furniſhed with dampers, with one common chimney, which ſtands in the centre of the croſs. The dampers are thin flat tiles;—the grates on which the Fuel is burned are compoſed of common bricks, placed edgewiſe;—and the paſſages leading to the fire-place, and to the aſh-pit, are cloſed by bricks which are made to ſlide in grooves.

Under the bottom of each boiler, which is quite flat, there are three flues, in the direction of its length; that in the middle, which is as wide as both the others, being occupied by the burning Fuel. The opening by which the Fuel is introduced is at the end of the boiler *fartheſt from the chimney;* and the flame running along the middle flue to the end of it, divides there, and returning in the two ſide flues to the hither end of the boiler, there riſes up into two other flues, in which it paſſes along the outſide of the boiler into the chimney. The boilers are furniſhed with wooden covers divided into two equal parts, united by hinges. In order that the four boilers may be tranſported with greater facility from place to place, (from one camp to another

other for inſtance,) they are not all preciſely of the ſame ſize, but one is ſo much leſs than the other, that they may be packed one in the other. The largeſt of them, which contains the three others, is packed in a wooden cheſt, which is made juſt large enough to receive it. In the ſmalleſt may be packed a circular tent, ſufficiently large to cover them all. In the middle of the tent there muſt be a whole through which the chimney muſt paſs. The four boilers, together with the tent, and all the apparatus and utenſils neceſſary for a Kitchen on this conſtruction for a regiment conſiſting of 1000 men, might eaſily be tranſported from place to place on an Iriſh car drawn by a ſingle horſe.

I have been the more particular in my account of this portable Kitchen, as I think it would be found very uſeful for troops in camp. The Right Honourable Mr. Thomas Pelham made a trial of one of them laſt ſummer for his regiment, (the Suſſex militia,) and found it to be very uſeful. The ſaving of Fuel was very conſiderable indeed; and the ſaving of trouble in cooking not leſs important. The firſt Experiment we made together in a ſingle boiler, fitted up for the purpoſe in the open air, in the middle of the court-yard of Lord Pelham's houſe in London.

I ought perhaps to have reſerved what I have here ſaid on the ſubject of theſe Military portable Kitchens for my next Eſſay, where it would more naturally have found its place; but being perſuaded of the great advantages that may be derived from them, I am unwilling to loſe a moment in recommending them to the attention of thoſe who have it in their power to bring them into uſe.

Thoſe who wiſh to know more about them may, I am confident, procure every information they can deſire reſpecting them, by applying to Mr. Pelham, or to any of the Officers of the Suſſex militia who were in camp with the regiment laſt ſummer.

There is one more invention for the uſe of armies in the field, which I wiſh to recommend, and that is *a portable boiler* of a light and cheap conſtruction, in which victuals may be cooked *on a march*. There are ſo many occaſions when it would be very deſirable to be able to give ſoldiers, haraſſed and fatigued with ſevere ſervice, a warm meal, when it is impoſſible to ſtop to light fires and boil the pot, that I cannot help flattering myſelf that a contrivance, by which the pot *actually boiling* may be made to keep pace with the troops as they advance, will be an acceptable preſent to every humane officer and wiſe and prudent general. Many a battle has undoubtedly been loſt for the want of a good comfortable meal of warm victuals to recruit the ſtrength and raiſe the ſpirits of troops fainting with hunger and exceſſive fatigue.

But to return from this digreſſion.—The form of the two principal boilers in the Kitchen of the FOUNDLING HOSPITAL is that of an oblong ſquare; that form which on ſeveral accounts I have reaſon to think preferable to all others for large boilers, but eſpecially on account of the facility of fitting them up with ſquare bricks, and of cleaning their flues, I firſt introduced in Ireland in ſeveral fire-places deſigned for different uſes, which I fitted up as models, in Dublin, during the viſit I made laſt ſpring to that country on the invitation of my friend Mr. Secretary Pelham.

The firſt of theſe oblong ſquare boilers is that which is fitted up in the court-yard of the Linen-hall at Dublin, *as a model for bleachers:* It is 8 feet wide, 10 feet long, and 2 feet deep; and it is furniſhed with a wooden cover, which ſhutting down in a groove in which there is a ſmall quantity of water, the ſteam is by theſe means confined in the boiler. This cover is moveable on its hinges, which are placed at the end of the boiler fartheſt from the door of the fire-place; and it is occaſionally lifted up by means of a rope, which goes over a compound pully which is fixed over the boiler at the top or ceiling of the room.

Under this boiler there are five flues which run in the direction of its length, and are arranged and conſtructed in the ſame manner as the flues of the new Brewhouſe boiler which I lately fitted up at Munich.—(See Fig. 21, Plate V.)—There are no flues round the outſide of this boiler; but the brick walls by which they are defended from the cold air are double, and the ſpace between them is filled with charcoal duſt.

The Fuel burns at the hither end of the middle flue, in an oval diſh-grate; and the flame running along in this flue under the middle of the boiler to the farther end of it, there divides, and returns in the two adjoining flues:—It then turns to the right and left, and going back again in the two outſide flues to the farther end of the boiler, goes out from under it, there, in two canals, which ſloping upwards conduct it to the flues of a *ſecond boiler* of equal dimenſions with the firſt, where it circulates, and warms the water which is deſigned for refilling the firſt boiler.

As theſe boilers are made of exceedingly thin ſheet copper, and *thin boilers* are ſtronger to reſiſt the effects of the Fire, and conſequently more durable, than very thick ones, they both together coſt much leſs than one ſingle boiler on the common conſtruction; and Mr. Duffin, Secretary to the Linen-board, who is a very active, intelligent man, and is himſelf engaged in a large concern in the bleaching buſineſs, ſhowed me a computation founded on actual Experiments which he himſelf made with this new boiler, by which he proved that the ſaving of Fuel which will reſult from the general introduction of theſe boilers in the bleaching trade throughout Ireland will amount to at leaſt fifty thouſand pounds ſterling a year.

In a LAUNDRY which I fitted up in the houſe belonging to the Dublin Society, (and which is deſigned to ſerve as a model for Laundries for private gentlemen's families,) there are alſo two oblong ſquare boilers, the one heated by the Fire, and the other by the ſmoke; and this ſmoke, after having circulated in the flues under the ſecond boiler, paſſes through a long flue (conſtructed like hot-houſe flues) which goes round two ſides of the *drying-room*, (which is adjoining to the *waſhing-room*,) and then paſſing through the wall of the drying-room into the ironing-room, it goes off into an open chimney. As the bottom of the ſecond boiler lies on a level with the top of the firſt, the warm water runs out of the ſecond to refill the firſt, by a tube furniſhed with a braſs cock, which greatly facilitates the filling of the principal boiler. The wooden covers of theſe boilers, which are double and moveable on hinges, are ſhut down in grooves in which there is water, and the ſteam being by theſe means confined, is forced to paſs off by a wooden tube ſtanding on a part of the cover which is faſtened down to the boiler with hooks, carries the ſteam upwards to the height of ſeven or eight feet, where it goes off laterally by another (horizontal) wooden tube, through the wall into the drying-room. As ſoon as this horizontal wooden tube has paſſed through the wall into the drying-room, it ends in a copper tube, about 3 inches in diameter, which, lying nearly in a horizontal poſition, conducts the ſteam through the middle of the drying-room in the direction of its length, and through a hole in a window at the end of the room into the open air.

The ſteam in paſſing through the drying-room in a metallic tube, (which is a good conductor of heat,) gives off its heat through the ſides of the tube to the air of the room, and the water which is condenſed runs off through the tube. By ſloping the tube *upwards*, inſtead of downwards, as by accident it was ſloped, the condenſed water, which is always nearly boiling hot, when it is condenſed, might be made to return into the boiler, which would be attended with a ſaving of heat, and conſequently of Fuel.

The furnace for heating the irons uſed in ſmoothing the linen, (or ironing, as it is called,) is a kind of oven built of bricks and mortar, the bottom of which is a ſhallow pan of caſt iron, 18 inches ſquare and about 3 inches deep, which is nearly filled with fine ſand. The Fire being made under this pan in a cloſed fire-place, as the ſand defends the upper ſurface of the pan from the cold air of the atmoſphere, the pan is commonly red-hot, and the irons, being ſhoved down through the ſand and placed in contact with this plate of red-hot metal, are heated in a very ſhort time, and at a ſmall expence of Fuel.

This contrivance might be uſed with great ſucceſs for covering the *hot plates* on which ſauce-pans are made to boil in many private Kitchens.

This ſtove, or oven, for heating the ſmoothing-irons, projects into the drying-room, but the door by which the irons are introduced, as well as that leading to the fire-place, and that leading to the aſh-pit, all open into the ironing-room.

The ſmoke goes off through the drying-room in an iron tube, and aſſiſts in warming the room and in drying the linen.

As it may ſometimes be neceſſary to heat the drying-room when neither the waſh-houſe boilers nor the ſtove for heating the ſmoothing-irons are heated, proviſion is made for that, by conſtructing a ſmall cloſed fire-place, deſigned merely for that purpoſe, which opens into the flue, by which the ſmoke from the boilers is carried round the drying-room. This fire-place (which is never uſed but when it is wanted for drying the linen) is ſituated juſt without the drying-room, under the end of the flue where it joins the ſecond boiler.—The opening at the top of its fire-place, by which the flame of the burning Fuel enters the under part of the flue, is kept cloſed by a ſliding plate of iron, or damper, when this fire-place is not uſed; and when it is uſed, the door which cloſes the opening into the fire-place of the firſt or principal boiler, and the regiſter in its aſh-pit door, are kept ſhut.

That the top of the principal boiler might not be too high above the pavement of the waſh-houſe for the laundreſſes to work in the boiler without being obliged to go up ſteps or ſtairs, the grate and the bottom of the flues under the boiler are nearly on a level with the pavement, and the aſh-pit is ſunk into the ground; and to render the approach to the opening into the fire-place more convenient in introducing the Fuel and lighting and managing the Fire, there is an area before the fire-place, about 3 feet ſquare and 2 feet deep, ſunk in the ground, and walled up on its ſides, into which there is a deſcent by ſteps. In two of the ſides of theſe vertical walls (thoſe on the right and left when you ſtand fronting the fire-place) there are vaults for containing Fuel, which extend ſeveral feet under the pavement. The ſteps which deſcend into this area are on the ſide of it, oppoſite the fire-place.

Areas of this kind are very neceſſary for all fire-places for large boilers, otherwiſe the top of the boiler will neceſſarily be raiſed too high above the level of the pavement to be approached with facility and convenience. Steps may be made, it is true, for approaching boilers which are placed higher; but theſe are always inconvenient, and take up more room, and coſt more than the execution of the plan here propoſed for rendering them unneceſſary.

The areas before the fire-place door of the large boilers in the Kitchen of the Foundling Hoſpital are occaſionally cloſed by trap-doors. As often as this is done there muſt be a number of ſmall holes bored in the door to permit the air neceſſary for feeding the Fire to deſcend into the aſh-pit; and when the bottom of the paſſage leading into the fire-place happens to lie above the level of the upper ſurface of this trap-door, the part of the door immediately under this opening, ſhould, to prevent accidents from live coals which may occaſionally fall out of the fire-place, be covered with a thin plate of ſheet-iron.

When large boilers are fitted up in ſituations where it is not poſſible to ſink an area in front of the fire-place, the maſs of brick-work in which the boiler is ſet muſt be raiſed, and ſteps muſt be made to approach it. When this is done, the upper ſtep ſhould be made very wide, (at leaſt two feet,) in order that there may be room to ſtand and work in the boiler; and for ſtill greater convenience, the ſteps ſhould be continued round three ſides of the boiler, when the boiler ſtands in a detached maſs of brick-work. The bottom of the door of the fire-place, ſhould, if poſſible, be above the upper flat ſurface of the upper ſtep; and to preſerve the ſymmetry of the whole, the aſh-pit door may be in the front of the upper ſtep, and the paſſage into the aſh-pit, (which will be long of courſe) may deſcend in a gentle ſlope. In this manner the Kitchen of the Hoſpital of *la Pièta* at *Verona* was conſtructed.

No inconvenience whatever attends the increaſe of the length of the paſſage into the aſh-pit, except it be that very trifling one,—(which ſurely does not deſerve to be mentioned,)—the increaſe of labour attending the removal of the aſhes; but the inconvenience would be very conſiderable which would unavoidably attend the diſcontinuation, or breaking off, of the ſteps round the hither end, or front of the boiler, which would be neceſſary in order to be able to place the aſh-pit door *directly under* the fire-place door, and to make a way to approach it.

The flues under the principal boiler of the Laundry in the Houſe of the Dublin Society, are not contrived ſo as to divide the flame and cauſe it to circulate in *two* currents; they run from ſide to ſide under it: the door of the fire-place is not in the middle, but on one ſide of the boiler, and near one end of it. The flame paſſing and returning (under the boiler) twice from its front to its oppoſite ſide, goes off at its end (that fartheſt from the fire-place) into a canal furniſhed with a damper, which canal, riſing upward at an angle of about 45 degrees, leads to the flues under the ſecond boiler. The bottom of the flues of the principal boiler are juſt on a level with the pavement of the waſh-houſe; and, in order that they may eaſily be cleaned out, and the bottom of the boiler ſcrubbed with a broom to free it from ſoot, the ends of the flues are, in building the fire-place, left open, and afterwards, when the boiler is ſet, they are cloſed by temporary (double) walls of dry bricks. To make theſe walls tight, the joinings of the bricks are plaſtered on the outſide with moiſt clay.

The ſides of the boilers are defended from the cold air by thin walls of bricks covered with wainſcot, and by filling the ſpace between theſe walls and the boiler with pounded charcoal. Were I to fit up theſe boilers again, I ſhould leave this ſpace void, or filled merely with air, forming ſeveral ſmall openings below, through which the flame and hot vapour from the flues might aſcend and ſurround the boiler. In the large boiler fitted up in the Linen-hall as a model for bleachers, this alteration is alſo neceſſary to render it complete; and as it might be made in a few hours, and almoſt without any expence, I cannot help expreſſing a wiſh that it might ſtill be done.

The ardent zeal for the proſperity of his country, and indefatigable attention to every thing that tends to promote uſeful improvement, which ſo eminently diſtinguiſh that enlightened patriot and moſt reſpectable ſtateſman, to whom the manufactures and commerce of Ireland, and the linen-trade in particular, are ſo much indebted, encourage me to hope that he will take pleaſure in giving his aſſiſtance to render the models for improving fire-places and ſaving Fuel, which I have had the ſatiſfaction of leaving in Ireland, as free from faults as they can poſſibly be made.

Though my ſtay in Ireland was too ſhort to conſtruct models of all the improvements I wiſhed to have introduced in that delightful and moſt intereſting iſland, yet the liberality with which my various propoſals were received, and the generous aſſiſtance I met with from all quarters, enabled me to do more in two months than I probably ſhould have been able to have effected in as many years in ſome other older countries, where the progreſs of wealth and of refinements have rendered it extremely difficult to get people to attend to uſeful improvements.

I wiſhed much to have been able to have fitted up the great Kitchen in the Houſe of Induſtry at Dublin, as the expence of Fuel is very conſiderable in that extenſive eſtabliſhment, where more than 1500 perſons are fed daily, at an average; but not having time to finiſh ſo conſiderable an undertaking, I thought it moſt prudent not to begin it. I fitted up one large boiler as a model at one end of one of the working-halls; but this was deſigned principally to ſhow how a large hall might be heated from a Kitchen fire-place, and from the very ſame Fire which is uſed for cooking *. The ſmoke from the fire-place is carried along horizontally on one ſide of the hall from one end of it to the other; and the boiler being cloſed by a cover which is ſteam-tight, the ſteam from the boiler is alſo forced along from one end of the hall to the other, in an horizontal leaden pipe, which runs parallel to the flue occupied by the ſmoke, and lies immediately over it. In warm weather, when the hall does not require to be heated, the ſmoke and ſteam go off immediately into the atmoſphere by a chimney adjoining to the fire-place, without paſſing through the hall.

To be able to equalize the heat in the hall, (which is very long and narrow,)—or to render it as warm at the end of it which is fartheſt from the fire-place, as at that next the Fire, I directed clothing for the ſteam tube of warm blanketing to be made in lengths of three or four feet, to be occaſionally put round it and faſtened by buttons.

By clothing or covering the ſteam tube more or leſs, as may be found neceſſary in thoſe parts of

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* This contrivance might eaſily be applied to the heating of hot-houſes, even though the hot-houſe ſhould happen to be ſituated at a conſiderable diſtance from the Kitchen.

the hall where the heat is greateſt, the ſteam being by this covering prevented from giving off its heat to the air through the tube, will go on farther and warm thoſe parts of the hall which otherwiſe would be not ſufficiently heated. The ſteam tube, which is conſtructed of very thin ſheet-lead, is about 3 inches in diameter, and inſtead of being laid exactly in a horizontal poſition, ſlopes a little upwards, juſt ſo much that the water which reſults from the condenſation of the ſteam may return into the boiler *.

The horizontal flue through which the ſmoke paſſes is a round tube of ſheet-iron, about 7 inches in diameter, divided, for the facility of cleaning it, in lengths of 12 or 15 feet, fixed nearly horizontally at different heights from the floor, or, in an interrupted line, in hollow pilaſters or ſquare columns of brick-work. A common hot-houſe flue, conſtructed of bricks and mortar, would have an-

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* I contrived a fire-place for heating one of the principal churches in Dublin on theſe principles with ſteam (but without making uſe of the ſmoke); and I promiſed to give a plan (which, I am aſhamed to ſay, I have not yet been able to finiſh) for heating the ſuperb new building deſtined for the meeting of the Iriſh Houſe of Commons.

One of the two chimney fire-places, which I fitted up in the hall in which the meetings of the Royal Iriſh Academy are held, will, I imagine, be found to anſwer very well for heating high rooms and large halls in private houſes. In this fire-place I have endeavoured, and I believe ſucceſsfully, to unite the advantages of an open fire with thoſe of a German ſtove. The grate uſed in fitting up this fire-place, and which is of caſt iron, and far from being unelegant in its form, and which coſt only *ſeven ſhillings and ſixpence ſterling*, is decidedly the beſt adapted for open chimney fire-places, where coals are uſed as Fuel, of any I have yet ſeen. By a letter I lately received from a friend in Ireland, I had the ſatisfaction to learn that theſe grates are coming very faſt into general uſe in that country.

ſwered equally well for warming the hall, but would have taken up too much room, which is the only reaſon it was not preferred to theſe iron tubes.

In conſtructing the boiler, (which is of thin ſheet-iron,) I made an Experiment which ſucceeded even beyond my expectation. The flues under the boiler—(and there are none round it)—are projections from the bottom of the boiler;—they are hollow walls of ſheet-iron, about 9 inches high, and an inch and three quarters thick, into which the liquid in the boiler deſcends, and which in fact conſtitute a part of the boiler. By this contrivance the flame is ſurrounded on all ſides, except at the bottom of the flues, (where the heat has little or no tendency to paſs,) by the liquid which is heated, and the fire-place is merely a flat maſs of brick-work. The grate is even with the upper ſurface of this maſs of brick-work, and the aſh-pit is the only cavity in it.

In conſtructing the boiler, proviſion was made, by omitting or interrupting the hollow walls or diviſions of the flues, in the proper places, to leave room for introducing the Fuel,—for the paſſage of the flame from one flue to another,—and from the laſt flue into the canal by which the ſmoke goes off into the chimney, or into the iron tubes by which the hall is occaſionally warmed.

One principal object which I had in view in this Experiment was to ſee if I could not contrive a boiler, which, being ſuſpended under a waggon or other wheel carriage, might ſerve for cooking for troops on a march; or which, being merely ſet down on the ground, a fire might be immediately kindled under it.

Thoſe who will take the trouble to examine the boiler in queſtion, will find that the principle on which it is conſtructed may eaſily be applied to the objects here mentioned. But it is not merely for portable boilers that this conſtruction would be found uſeful; I am convinced that it would be very advantageous for the boilers of ſteam-engines,—for diſtilleries,—and for various other purpoſes. As the eſcape of heat into the brick-work is almoſt entirely prevented, and as the ſurface of the boiler on which the heat is made to act is greatly increaſed by means of the hollow walls, the liquid in the boiler is heated in a very ſhort time, and with a ſmall quantity of Fuel.

There is ſtill another advantage attending this conſtruction, which renders it highly deſerving the attention of diſtillers. By making the tops of the flues arched inſtead of flat, (which may eaſily be done, and which is actually done in the boiler in queſtion,) or in the form of the roof of a houſe, as the hotteſt part of the flame will of courſe always occupy the upper part of the flues, and as the thick or viſcous part of the liquor in the boiler, that which is in moſt danger of being burned to the bottom of the boiler, and giving a bad taſte to the ſpirit which comes over, cannot well lie on the convex or ſloping ſurface of theſe flues, there will be leſs danger of an accident which diſtillers have hitherto found it extremely difficult to prevent.

In conſtructing boilers on theſe principles for diſtillers, it will probably be found neceſſary to increaſe very much the thickneſs of the hollow walls of the flues; and perhaps to make them even deeper than the level of the bottom of the flues, in order more effectually to prevent the thick matter which will naturally ſettle in thoſe cavities from being expoſed to too great a heat.

A ſimilar advantage will attend large boilers conſtructed on theſe principles for making thick ſoups for hoſpitals; theſe ſoups being very apt to burn to the bottoms of the boilers in which they are prepared.

I made another Experiment in the Houſe of Induſtry in Dublin, which I wiſhed much to have had time to have proſecuted farther. Finding that the expence for wheaten bread for the Houſe was very great, (amounting, in the year 1795, to no leſs than 3841 l. ſterling,) I ſaw that a very conſiderable ſaving might be made by furniſhing thoſe who were fed at the public expence with oaten cakes, (a kind of bread to which they had always been uſed,) inſtead of rendering them dainty and ſpoiling them by giving them the beſt wheaten bread that could be procured, as I found had hitherto been done. But to be able to furniſh oaten cakes in ſufficient quantities to feed 1500 perſons, ſome more convenient method of baking them than that commonly practiſed was neceſſary, and one in which the expence of Fuel might be greatly leſſened.

With a view to facilitate this important change in the mode of feeding the numerous objects of charity, and of *correction*, who were ſhut up together within the walls of that extenſive eſtabliſhment, I conſtructed what I would call a *Perpetual Oven*.

In the centre of a circular, or rather cylindrical maſs of brick-work, about eight feet in diameter, which occupies the middle of a large room on the ground floor, I conſtructed a ſmall circular cloſed fire-place for burning either wood, peat, turf, or coals. The diameter of the fire-place is about eleven inches, the grate being placed about ten inches above the floor, and the top of the fire-place is contracted to about four inches. Immediately above this narrow throat, ſix ſeparate canals (each furniſhed with a damper, by means of which its opening can be contracted more or leſs, or entirely cloſed) go off horizontally, by which the flame is conducted into ſix ſeparate ſets of flues, under ſix large plates of caſt iron, which form the bottoms of ſix Ovens on the ſame level, and joining each other by their ſides, which are concealed in the cylindrical maſs of the brick-work. Each of theſe plates of caſt iron being in the form of an equilateral triangle, they all unite in the centre of the cylindrical maſs of brick-work, conſequently the two ſides of each unite in a point at the bottom of it, forming an angle of ſixty degrees.

The flame, after circulating under the bottoms of theſe Ovens, riſes up in two canals concealed in the front wall of each Oven, and ſituated on the right and left of its mouth, and after circulating again in ſimilar flues on the upper flat ſurface of another triangular plate of caſt iron which forms the top of the Oven, goes off upwards by a canal furniſhed with a damper into a hollow place, ſituated on the top of the cylindrical maſs of the brick-work, from which it paſſes off in a horizontal iron tube, about ſeven inches in diameter, ſuſpended near the ceiling of the room, into a chimney ſituated on one ſide of the room.

Theſe ſix Ovens, which are contiguous to each other in this maſs of brick-work, are united by their ſides by thin walls made of tiles about 1½ inches thick, and 10 inches ſquare, placed edgewiſe, and each Oven having its ſeparate canal, furniſhed with a regiſter communicating with the fire-place, any one or more of them may be heated without heating the others, or the heat may be turned off from one of them to the other in continual ſucceſſion; and, by managing matters properly, the proceſs of baking may be *uninterrupted.* As ſoon as the bread is drawn out of one of the Ovens, the Fire may immediately be turned under it to heat it again, while that from under which the Fire is taken is filled with unbaked loaves, and cloſed up.

A principal object which I had in view in conſtructing this Oven was to prevent the great loſs of heat which is occaſioned in large Ovens, by keeping the mouth of the Oven open for ſo conſiderable a length of time as is neceſſary for putting in and drawing out the bread. As one of theſe ſmall Ovens contains only five large loaves, or cakes, it may be charged, or the bread when baked may be drawn, in a moment; and, during this time, the other five Ovens are kept cloſed, and conſequently are not loſing heat; *one* of them is heating, while the other *four* are filled with bread in different ſtages of the proceſs of baking.

When I conſtructed this Oven, though I had no doubt of its being perfectly well calculated for the uſe for which it was principally deſigned,—baking oaten cakes, which are commonly baked on heated iron plates,—yet I was by no means ſure it would anſwer for baking common bread in large thick loaves. I had not made the Experiment. And though I could not conceive that any thing more could be neceſſary in the proceſs of baking than *heat*,—and here I was abſolutely maſter of every degree of it that could poſſibly be wanted, and could even regulate the ſucceſſion of different degrees of it at pleaſure,—I thought it probable that ſome particular management might be required in baking bread in theſe metallic ovens, a knowledge of which could only be acquired by experience.

What ſerved to ſtrengthen theſe ſuſpicions was a diſcovery which had accidentally been made by the cook of the Military Academy. In the courſe of *his* experiments, he found that my Roaſter is admirably well calculated for baking pies, puddings, and paſtry of all kinds;—provided however that the Fire be managed *in a certain way;*—for when the Fire is managed in the ſame manner in which it ought to be managed in roaſting meat, pies and paſtry will abſolutely be ſpoiled. After repeated failures and diſappointments, and after having loſt all hopes of ever being able to ſucceed in his attempts, the cook (by mere accident, as he aſſured me) diſcovered the important ſecret;—and important he certainly conſiders it to be, and feels no ſmall degree of ſatisfaction,—not to ſay pride,—in having been ſo fortunate as to make the diſcovery. He muſt pardon me if I take the liberty,—even without his permiſſion,—to publiſh it to the world for the good of mankind.

The Roaſter muſt be well heated before the pies or paſtry are put into it, and the blowers muſt never be quite cloſed, during the proceſs.

I have lately found that by uſing ſimilar precautions, bread may be perfectly well baked in metallic Ovens, ſimilar to that in the Houſe of Induſtry in Dublin.

Thinking it more than probable that means might be deviſed for managing the heat in ſuch a manner as to perform that proceſs in Ovens conſtructed on theſe principles, and heated *from without;* and conceiving that not only a great ſaving of Fuel, but alſo ſeveral other very important advantages, could not fail to be derived from that diſcovery, on my return to Munich from England, in Auguſt laſt, I immediately ſet about making Experiments, with a view to the inveſtigation of that ſubject; and I have ſo far ſucceeded in them, that for theſe laſt four months my table has been ſupplied entirely with bread baked in my own houſe, by my cook, in an Oven conſtructed of thin ſheet-iron, which is heated (like my Roaſters) from without;—and I will venture to add, that I never taſted better bread. All thoſe who have eaten of it have unanimouſly expreſſed the ſame opinion of it. It is very light,—moſt thoroughly baked without being too much dried,—and I think remarkably well-taſted. The loaves, which are made ſmall in order that they may have a greater proportion of cruſt, (which, when the bread is baked in this way, is ſingularly delicate,) are placed in the Oven on circular plates of thin ſheet-iron, raiſed about an inch on ſlender iron feet. Were the loaf placed on the bottom of the Oven, the under cruſt would preſently be burnt to a coal, and the bread ſpoiled. A precaution abſolutely neceſſary in baking bread in the manner here recommended, is to leave a paſſage for the ſteam generated in the proceſs of baking to eſcape. This may be done either by conſtructing a ſteam-chimney for that purpoſe, furniſhed with a damper; or ſimply by making a regiſter in the door of the Oven.

As this is not the proper place to enlarge on this ſubject, I ſhall leave it for the preſent; but I cannot help expreſſing a wiſh, that what I have here advanced may induce others, eſpecially *Bakers*, who may find their own advantage in the proſecution of theſe intereſting and important inveſtigations, to turn their attention to them.

How exceedingly uſeful would my Roaſters be, and Ovens conſtructed on the principles here recommended, on ſhipboard!—Having ſerved a campaign (as a volunteer) in a large fleet, (that commanded by Admiral Sir Charles Hardy in the year 1779;) and having made ſeveral long ſea voyages, I have had frequent opportunities of ſeeing how difficult it is in bad weather to cook at ſea; and it is eaſy to imagine how much it would contribute to the comfort of ſeafaring people, eſpecially at times when they are expoſed to the greateſt fatigues and hardſhips, to enable them to have their tables well ſupplied with warm victuals.

In order that the motion of the veſſel might not derange any part of the apparatus uſed in the proceſs of cooking at ſea in my Roaſters, the form of the Roaſter ſhould be that of a perfect cylinder, and the dripping-pan in which the meat is placed ſhould be a longitudinal ſection of another cylinder, leſs in diameter than the Roaſter by about an inch, and ſuſpended on two pivots in the axis of the Roaſter, in ſuch a manner that the dripping-pan may ſwing freely in the Roaſter, without touching its ſides. The Roaſter ſhould be placed in the brick-work, with its axis in the direction of the length of the ſhip; and to prevent the gravy from being thrown out of the dripping-pan when the veſſel pitches, its hollow cavity ſhould be divided into a number of compartments, by partitions running acroſs it from ſide to ſide.

It remains for me to give ſome account of the Kitchen which I fitted up in the Houſe of the Dublin Society, as a model for private families;—and alſo of a Cottage Fire-place, and a Lime-kiln, which I conſtructed, as models for imitation, in the court-yard of that public building.

With regard to the Kitchen, it is neceſſary that I ſhould remark at ſetting out, that it was not intended ſo much to ſerve as a model complete of a convenient Kitchen for a private family, as to diſplay a variety of uſeful inventions, all or any of which may at pleaſure be eaſily adopted, in Kitchens of all kinds and of all dimenſions. I thought this would be more uſeful than any ſimple model of a Kitchen I could contrive.

It is however a very complete Kitchen; and though there are ſome contrivances belonging to it which might have been omitted, yet they will all, I am confident, be found uſeful for the different purpoſes for which they were particularly deſigned; and, in a Kitchen for a large family, would often come into uſe.

The general diſpoſition of the various parts of this Kitchen I conſider as being quite perfect. It is the ſame as that of the Hoſpital of *la Pièta* at *Verona;* and of a very complete private Kitchen which was built about two years ago at Munich, under my direction, in the houſe of BARON LERCHENFELD, Steward of the Houſehold to HIS

MOST SERENE HIGHNESS THE ELECTOR. In my next Eſſay, which will treat excluſively of the Conſtruction of Kitchen Fire-places, and of Kitchen Utenſils, I ſhall give a particlar detailed account of the manner in which the various Boilers,—Steam-boilers,—Saucepans,—Oven,—Roaſters, &c.—are diſpoſed and connected in the maſs of brick-work in theſe Kitchens; and ſhall accompany theſe deſcriptions with a ſufficient number of Plates to render them perfectly intelligible.

Cottage Fire-place, and Iron Pot, for cooking for the Poor.

THE Cottage Fire-place which I fitted up as a model, in the court-yard of the Houſe of the Dublin Society, was not quite finiſhed when I left Ireland; but an idea may be formed from what was done of the general principles on which ſuch Fire-places may be conſtructed. On each ſide of the open chimney Fire-place, (which being ſmall, was built in the middle of one much larger, which was conſtructed to repreſent a large open Fire-place, ſuch as are now general in Cottages,) I fitted up an Iron Pot on a peculiar conſtruction, caſt by Mr. Jackſon of Dublin, and deſigned for the uſe of a poor family in cooking their victuals. This Pot is nearly of a cylindrical form, about ſixteen inches in diameter, and eight inches deep; and under its bottom, which is quite flat, there is a thin ſpiral projection, which was caſt with the Pot, and ſerves inſtead of feet to it, the turns of which, when the Pot is ſet down on a flat ſurface, form a ſpiral flue in which the flame circulates under the bottom of the Pot. This projection, which is near half an inch thick where it is united with the bottom of the Pot, and leſs than a quarter of an inch below where its lower edge reſts on the ground, is about four inches wide, or rather deep. This projection was made tapering, in order to its being more eaſily caſt. To defend the outſide of this Pot from the cold air, the Pot is incloſed in a cylinder of thin ſheet-iron, equal in diameter to the extreme width of the Pot at its brim,—juſt as high as the depth of the Pot and of its ſpiral flues taken together. The Pot is faſtened to this cylindrical caſe by being driven into it with force, a rim in the form of a flat hoop, about an inch and an half deep and a little tapering, being caſt on the outſide of the Pot at its brim, the external ſurface of which was fitted exactly into the top of this cylinder. This projection is uſeful, not only in uniting the Pot to its cylindrical caſe, but alſo to keep this cylindrical caſe at ſome ſmall diſtance from the ſides of the Pot, by which means the heat is more effectually confined.

To be able to move about this Pot from place to place, it has two handles which are rivetted to the outſide of its cylindrical caſe; and it is provided with a wooden cover.

I am ſenſible that I often expoſe myſelf to criticiſm by anticipating what would more naturally find its place elſewhere. But what I have here ſaid in regard to this Iron Pot is intended merely as hints to awaken the curioſity and excite the attention of ingenious men,—of ſuch as take pleaſure in exerciſing their ingenuity in contriving and perfecting uſeful inventions, and who delight in contemplating the progreſs of human induſtry.

Model of a perpetual Lime-kiln.

THE particular objects principally had in view in the conſtruction of this Lime-kiln (which ſtands in the court-yard of the Dublin Society) were, *firſt*, to cauſe the Fuel to burn in ſuch a manner as to conſume the ſmoke, which was done by obliging the ſmoke to deſcend and paſs through the Fire, in order that as much heat as poſſible might be generated.—Secondly, to cauſe the flame and hot vapour which riſe from the Fire to come into contact with the lime-ſtone by a very large ſurface, in order to economiſe the heat, and prevent its going off into the atmoſphere; which was done by making the body of the Kiln in the form of a hollow truncated cone, and very high in proportion to its diameter; and by filling it quite up to the top with lime-ſtone, the Fire being made to enter near the bottom of the cone.

Thirdly, to make the proceſs of burning lime *perpetual*, in order to prevent the waſte of heat which unavoidably attends the cooling of the Kiln in emptying and filling it, when, to perform that operation, it is neceſſary to put out the Fire.

And, fourthly, to contrive matters ſo that the lime in which the proceſs of burning is *juſt finiſhed*, and which of courſe is ſtill *intenſely hot*, may, in *cooling*, be made to give off its heat in ſuch a manner as to aſſiſt in heating the freſh quantity of cold lime-ſtone with which the Kiln is repleniſhed as often as a portion of lime is taken out of it.

To effectuate theſe purpoſes, the Fuel is not mixed with the lime-ſtone, but is burned in a cloſed fire-place, which opens into one ſide of the Kiln, ſome diſtance above the bottom of it. For large Lime-kilns on theſe principles there may be ſeveral fire-places, all opening into the ſame cone, and ſituated on different ſides of it; which fire-places may be conſtructed and regulated like the fire-places of the furnaces uſed for burning porcelaine.

At the bottom of the Kiln there is a door, which is occaſionally opened to take out the lime.

When, in conſequence of a portion of lime being drawn out of the Kiln, its contents ſettle down or ſubſide, the empty ſpace in the upper part of the Kiln, which is occaſioned by this ſubſtraction of the burned lime, is immediately filled up with freſh lime-ſtone.

As ſoon as a portion of lime is taken away, the door by which it is removed muſt be immediately ſhut, and the joinings well cloſed with moiſt clay, to prevent a draught of cold air through the Kiln. A ſmall opening however muſt be left, for reaſons which I ſhall preſently explain.

As the Fire enters the Kiln at ſome diſtance from the bottom of it, and as the flame *riſes* as ſoon as it comes into this cavity, the lower part of the Kiln (that below the level of the bottom of the fire-place) is occupied by lime already burned, and as this lime is intenſely hot, when, on a portion of lime from below being removed, it deſcends into this part of the Kiln, and as the air in the Kiln, to which it communicates its heat, muſt *riſe upwards* in conſequence of its being heated, and paſs off through the top of the Kiln, this lime in cooling is, by this contrivance, made to aſſiſt in heating the freſh portion of cold lime-ſtone with which the Kiln is charged. To facilitate this communication of heat from the red-hot lime juſt burned to the lime-ſtone above in the upper part of the Kiln, a gentle draught of air through the Kiln from the bottom to the top of it muſt be eſtabliſhed by leaving an opening in the door below, by which the cold air from without may be ſuffered to enter the Kiln. This opening (which ſhould be furniſhed with ſome kind of a regiſter) muſt be very ſmall, otherwiſe it will occaſion too ſtrong a draught of cold air into the Kiln, and do more harm than good; and it will probably be found to be beſt to cloſe it entirely, after the lime in the lower part of the Kiln has parted with a certain proportion of its heat.

Conceiving the improvement of Lime-kilns to be a matter of very great national importance, eſpecially ſince the uſe of lime as manure has become ſo general, I intend to devote the firſt leiſure time

I can ſpare to a thorough inveſtigation of that ſubject;—in the mean time, I have here thrown out the looſe ideas I have formed reſpecting it, in order that they may be examined, corrected, and improved upon by others who may be engaged in the ſame purſuits.

The model I cauſed to be conſtructed in the court-yard of the Dublin Society, is, I am ſenſible, very imperfect. It was built in a great hurry, being begun and finiſhed the ſame day,—the day but one before I left Ireland;—but I am now engaged in conſtructing a Lime-kiln on the ſame principles, (for the uſe of the farm in the Engliſh Garden at Munich,) which I ſhall take pains to make as perfect as poſſible; and ſhould it be found to anſwer as well as I have reaſon to hope it will, I ſhall not fail to give a particular account of it to the Public, accompanied with drawings, and all the details which ſhall be neceſſary in order to give the moſt ſatisfactory account of the reſult of the Experiment.

Theſe inveſtigations will be the more intereſting, and their reſults more generally uſeful, as the diſcovery of a mine of pit-coal in the neighbourhood of Munich, which is now worked with ſucceſs, has put it in my power to uſe coal as Fuel, as well as wood and turf, in the Experiments I ſhall make in burning lime in this Kiln.

For the information of thoſe who may be diſpoſed to engage in theſe purſuits, I have publiſhed the annexed ſketch of the Lime-kiln in queſtion, which is now actually building (ſee Plate VI.). I thought it right to do this, that we might ſtart fair; and I can aſſure my competitors in this race, that I ſhall feel no ill will on ſeeing them get before me.

If I do not deceive myſelf, the laudable exertions of others afford me almoſt as much pleaſure as my own purſuits;—at leaſt I am quite certain that when I can flatter myſelf that I have had any,—even the ſmalleſt ſhare,—in *exciting* thoſe exertions, the ſatisfaction I feel in contemplating them is inexpreſſible.

Fig. 1.

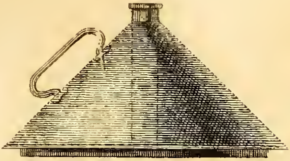
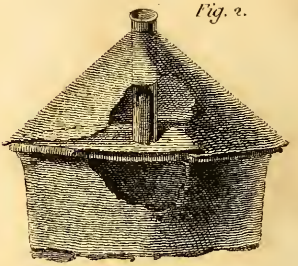


Fig. 2.



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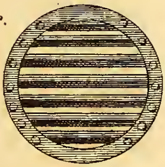
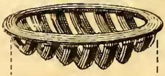


Fig. 4.



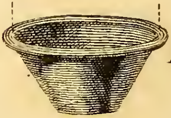


Fig. 5.

Fig. 6.

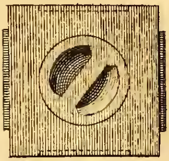


Fig. 7.

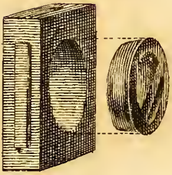
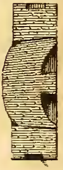


Fig. 8.



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DESCRIPTION OF THE PLATES.

PLATE I.

FIG. 1. A view of a double cover for a boiler or ſaucepan. In this deſign the rim is ſeen which enters the boiler, and the tube by which the ſteam goes off is ſeen in part (above),—and is in part indicated by dotted lines. (See page 18.)

Fig. 2 ſhows this cover placed on its boiler. Part of the ſide of the cover is repreſented as wanting, in order that the ſteam tube might be better ſeen. The height of this cover is repreſented as being equal to *one-half* its diameter; but I have found *one-third* of its diameter quite ſufficient for its height.

Fig. 3 and Fig. 4 are views of my circular diſhing-grates for cloſed kitchen fire-places. They may be made of any ſize, from 5 inches to 18 inches in diameter, according to the ſize of the boiler. The rules I have in general followed, in determining the ſize proper for the grate for any (circular) boiler, has been to make its diameter equal to half the diameter of the boiler at the brim. (See page 41.)

Fig. 5 is an inverted hollow cone of thin ſheet-iron, which is placed immediately under the grate, its brim being made to receive the circular rim of the grate. When the fire-place is large, this inverted cone may be made of fire-ſtone, or conſtructed of bricks and mortar. For ſmall fire-places it may be made of earthen ware, which is perhaps the very beſt material for it that can be found. (See page 43.)

Fig. 6, Fig. 7, and Fig. 8, are views and ſections of a perforated tile, with its ſtopper, ſuch as are uſed for cloſing the entrance by which the Fuel is introduced into cloſed kitchen fire-places. The diameter of the circular opening, or hole in the tile, may be from 6 to 7 inches. (See page 30.)

PLATE II.

The various Figures, from No. 9 to No. 16 of this Plate, ſhow the conſtruction of an aſh-pit door, with its regiſter. (See page 31.)

Fig. 9 is a front view of the door with its regiſter.—The whole is conſtructed of ſheet-iron, except the four narrow pieces at the four corners, which hold down in its place the circular plate of the regiſter; and the ſmall circular plate (as large as an half-crown) in the center of the regiſter, which are made of braſs, on account of that metal not being ſo liable to ruſt as iron.

Fig. 10 is a ſide view of the backſide of the door, fixed in its frame, in which the manner of its being ſhut in its frame is ſeen, and the iron ſtraps,

Plate 2.

Fig. 9.

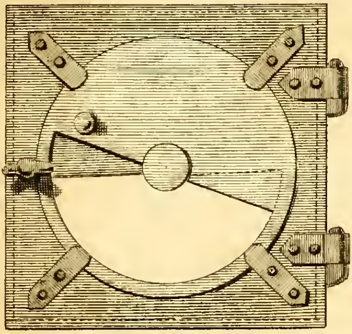


Fig. 10.

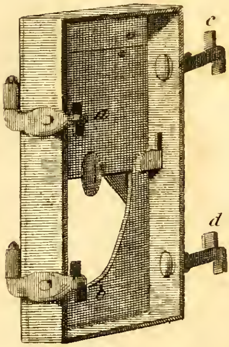


Fig. 11.

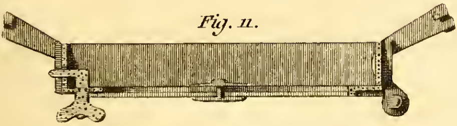


Fig. 12.

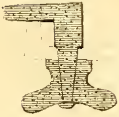


Fig. 13.

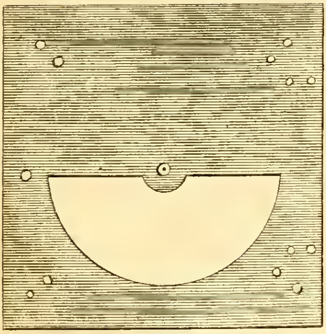


Fig. 14.

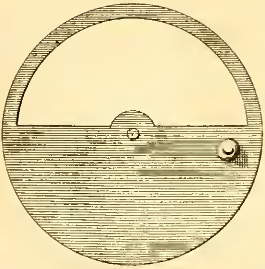


Fig. 15.

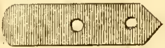
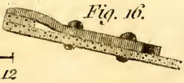
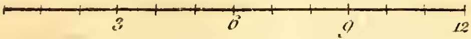


Fig. 16.



Scale of Inches



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a, *b*, *c*, *d*, are ſeen, by which the frame is faſtened in the brick-work.

Fig. 11 is an horizontal ſection through the middle of the door and its frame, and through the button which ſerves for ſhutting the door.

Fig. 12 is a ſection of this button, on an enlarged ſcale, ſhowing the manner in which it is conſtructed.

Fig. 13 is the plate of ſheet-iron which forms the front of the door, with the holes in it, by which the other parts of the machinery are fixed to it.

Fig. 14 is the circular plate which forms the regiſter—to this plate is fixed a projecting knob, or button, (repreſented in the Figure,) by which it is turned about.

Fig. 15 and Fig. 16 ſhow, on an enlarged ſcale, one of the four pieces of braſs by which the circular plate of the regiſter is kept down in its place.

In conſtructing theſe regiſter doors, and in general all iron doors for fire-places, great and ſmall, the door ſhould never ſhut in a rabbet, or groove, in the frame, but ſhould merely *ſhut down on the front edge of the frame*, which edge, by grinding it on the flat ſurface of a large flat ſtone, ſhould be made quite level to receive it. If this be done, and if the plate of iron which conſtitutes the door be made quite flat, and if it be properly fixed on its hinges, the door will always ſhut with facility and cloſe the opening with preciſion, notwithſtanding the effects of the expanſion of the metal by heat; but this cannot be the caſe when the doors of fire-places are fitted in grooves and rabbets.

Where the heat is very intenſe, the frame of the door ſhould be made of fire-ſtone; and that part of the door which is expoſed naked to the fire ſhould be covered either with a fit piece of fire-ſtone, faſtened to it with clamps of iron, or a ſufficient number of ſtrong nails, with long necks and flat heads, or of ſtaples, being driven into that ſide of the plate of iron which forms the door which is expoſed, ſhould be covered with a body about 2 inches thick of ſtrong clay mixed with a due portion of coarſe powder of broken crucibles, which maſs will be held in its place by the heads of the nails and by the projecting ſtaples. This maſs being put on wet, and gently dried, the cracks being carefully filled up as they appear, and the whole well beaten together into a ſolid maſs, will, when properly burned on by the heat of the fire, form a covering for the door which will effectually defend it from all injury from the fire; and the door ſo defended will laſt ten times longer than it would laſt without this defence.

The inſide doors of the two Brew-houſe Fire-places which I have fitted up at Munich are both defended from the heat in this manner; and the contrivance, which has anſwered perfectly all that was expected from it, has not been found to be attended with any inconvenience whatever.

Plate 3.

Fig. 17.

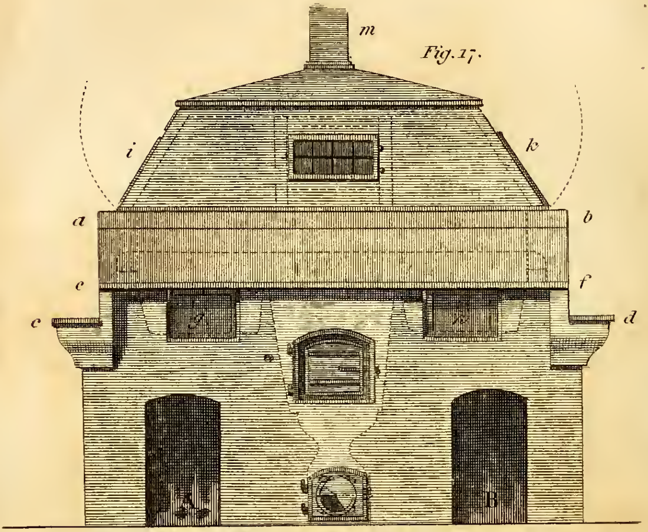

Fig. 18.

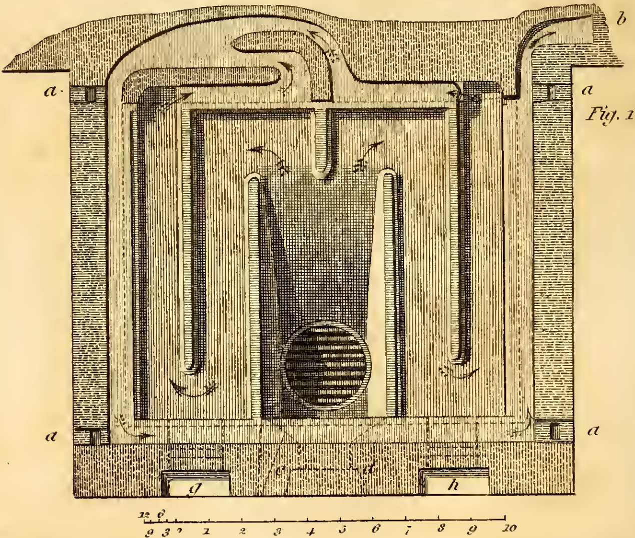

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PLATE III.

Fig. 17 is a front view of the new boiler of the brew-houſe called Neuheuſel, or rather of its fire-place and cover (the boiler being concealed in the brick-work). The inſide door of the fire-place is here repreſented ſhut; and, in order that it might appear, the outſide door is taken off its hinges, and is not ſhown. The two vaulted galleries, A, B, in the ſolid maſs of the brick-work, on the right and left of the fire-place, (which were made to ſave bricks,) ſerve for holding fire-wood. The partition walls of the fire-place and the different flues,—as alſo a ſection of the boiler, are repreſented by dotted lines. The ſmall circular hole on the left of the fire-place door is the window opening into the fire-place, by which the burning Fuel may be ſeen.

a, *b*, is the wooden curb of the boiler: *c*, *d*, a platform on which the men ſtand when they work in emptying the boiler, &c.: *e*, *f*, is a platform which ſerves as a paſſage from one ſide of the boiler to the other. This platform, which is about 18 inches wide, is 12 inches higher than the other platforms, in order that the openings *g* and *h*, into the flues, may remain free. Theſe openings, which are opened only occaſionally, that is to ſay, when the flues want cleaning, are kept cloſed by double brick-walls. Theſe walls are expreſſed in the following Figure.

Fig. 18. This is a horizontal ſection of the fire-place at a level with the bottom of the boiler. *a*, *a*,

a, *a*, *a*, *a*, are four openings by which the flues, which, in the firſt arrangement of this fire-place, went round the outſide of the boiler, was occaſionally cleaned: *b* is the canal by which the ſmoke went off into the chimney.

The entrance into the fire-place, and the conical perforation in the wall of the fire-place which ſerves as a window for obſerving the fire, are marked by dotted lines. The poſition of the outſide door of the fire-place is marked by a dotted line, *c*, *d*. The circular diſhing-grate is ſeen in its place; and the walls of the flues under the boiler are all ſeen. The crooked arrows in the flues ſhow the direction of the flame. (See page 100.)

PLATE IV.

Fig. 19 is a vertical ſection of the boiler repreſented in the foregoing Plate (Fig. 17.). This ſection is taken through the middle of the boiler, of the fire-place, and of the cover of the boiler. A is the aſh-pit, with a ſection of its regiſter door. B is the fire-place, and its circular diſhing-grate. C is the entrance by which the Fuel is introduced, with ſections of its two doors. D is a ſpace left void to ſave bricks. E is the boiler, and F its wooden cover. *m* is the ſteam chimney, which is furniſhed with a damper. R, R, is the vertical wall of the houſe againſt which the brick-work in which the boiler is fixed is placed.

a, *b*, is the curb of timber in which the boiler is ſet.

Plate 4.

Fig. 19.

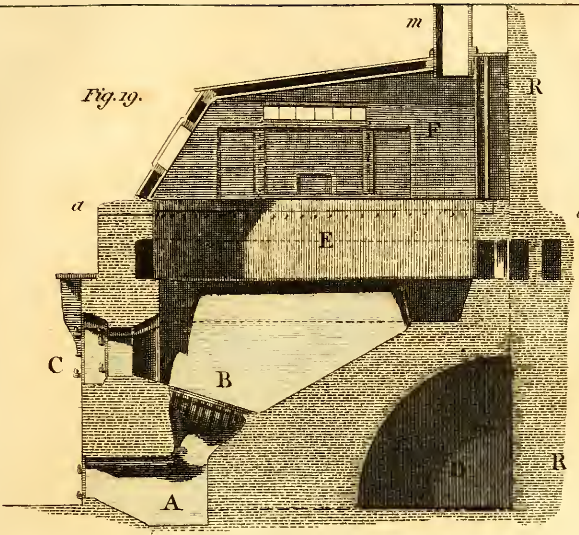

Fig. 20.

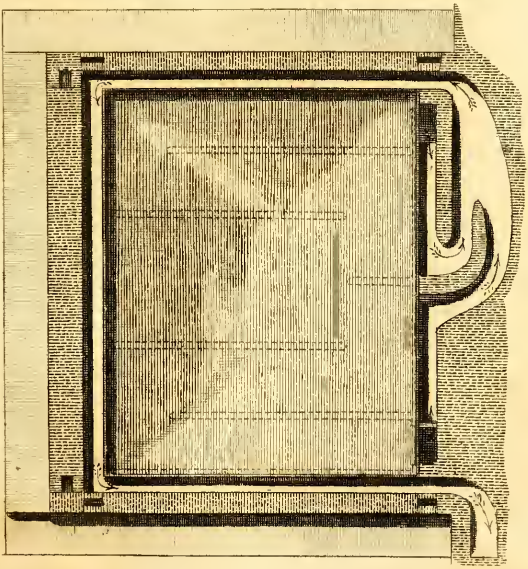

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Plate 5.

Fig. 24.

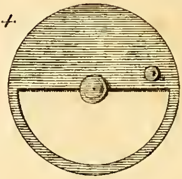


Fig. 23.

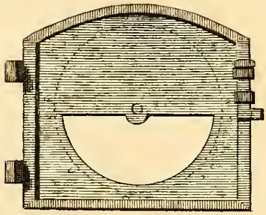
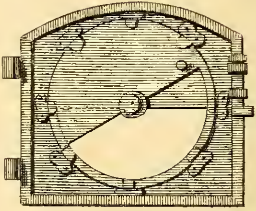
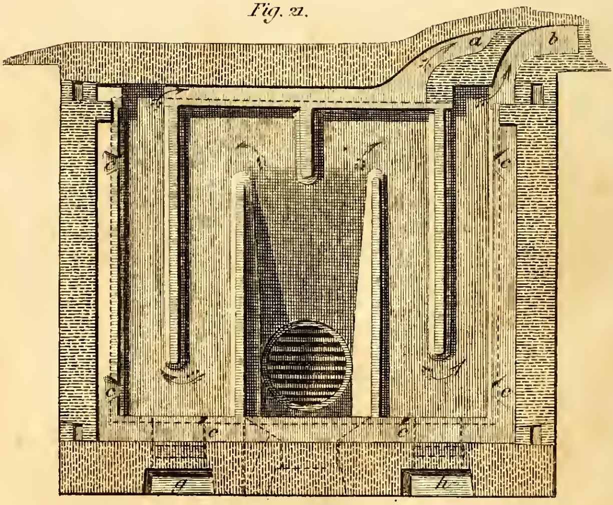


Fig. 22.



6 12 24 Inches

Fig. 21.



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The manner in which the cover of the boiler is conſtructed, as well as its form, and the door and windows which belong to it, are all ſeen diſtinctly in this Figure.

Fig. 20 is an horizontal ſection of this fire-place taken on a level with the bottom of the flue which goes round the outſide of the boiler, in which flue, before the fire-place was altered, the flame circulated. The flues under the boiler are, in this Figure, indicated by dotted lines.

PLATE V.

Fig. 21 is a horizontal ſection of the fire-place of the brewhouſe boiler, at a level with the top of the flues under the boiler, *after the flue round the outſide of the boiler had been ſtopped up*, or rather the flame prevented from circulating in it. This Figure ſhows the actual ſtate of the fire-place at the preſent time. (See page 126.)

The crooked arrows ſhow the direction of the flame in the flues.—*a*, *b*, are the two canals (each of which is furniſhed with a damper) by which the ſmoke goes off into the chimney;—and *c*, *c*, *c*, *c*, *c*, *c*, are ſix ſmall openings communicating with the flues, by which the flame and hot vapour can paſs up into the cavity on the outſide of the boiler which formerly ſerved as a flue.

Fig. 22 is a front view of the aſh-pit door of this brewhouſe fire-place, with its regiſter. This door is cloſed by means of a latch of a particular conſtruction, which is ſhown in the Figure.

Fig.

Fig. 23 is the door without its regiſter;—and

Fig. 24 the circular plate of the regiſter repreſented alone.

This aſh-pit door ſhuts againſt the front edge of its frame, and not into it; the reaſons for preferring this method of fitting the door to its frame have already been explained. (See deſcriptions of the Plate II.)

PLATE VI.

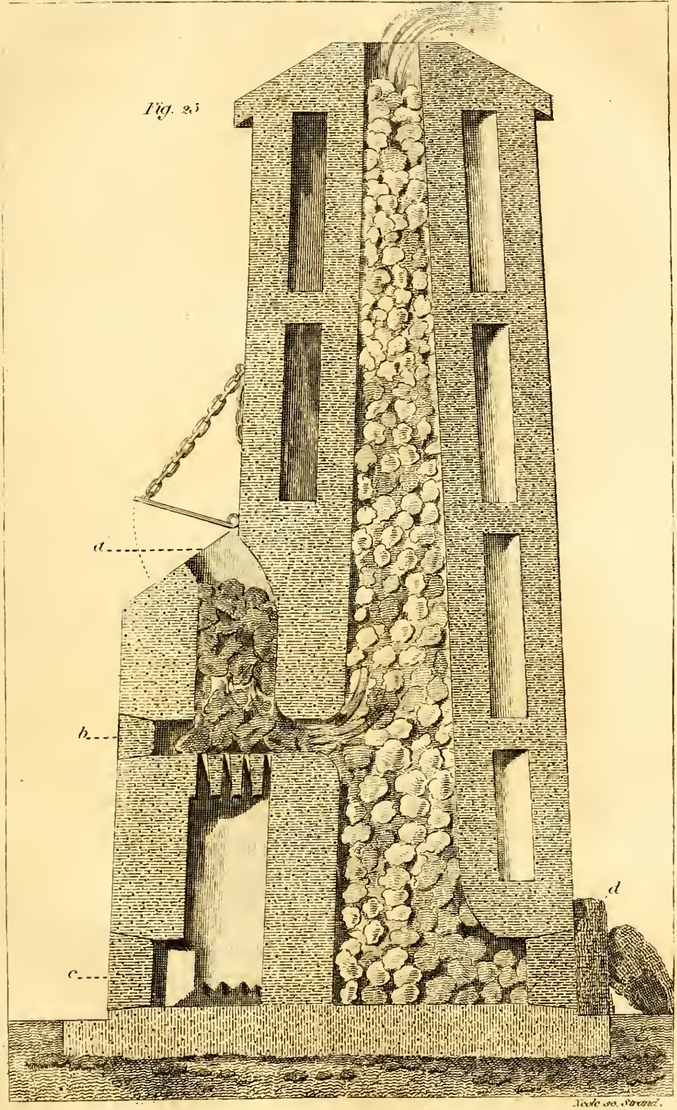
Fig. 25 is a ſection of a ſmall lime-kiln, built, or rather now building, at Munich, for the purpoſe of making experiments. The height of the kiln is 15 feet;—its internal diameter below, 2 feet,—and above, 9 inches. In order more effectually to confine the heat, its walls, which are of bricks and very thin, are double, and the cavity between them is filled with dry wood aſhes. To give greater ſtrength to the fabric, theſe two walls are connected in different places by horizontal layers of bricks which unite them firmly.

a, is the opening by which the fuel is put into the fire-place. Through this opening the air *deſcends* which feeds the fire. The fire-place is repreſented nearly full of coals, and the flame paſſing off laterally into the cavity of the kiln, by an opening made for that purpoſe at the bottom of the fire-place.

The opening above, by which the fuel is introduced into the fire-place, is covered by a plate of iron,

Plate 6.

Fig. 25



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iron, moveable on hinges; which plate, by being lifted up more or leſs by means of a chain, ſerves as a regiſter for regulating the fire.

A ſection of this plate, and of the chain by which it is ſupported, are ſhown in the Figure.

b is an opening in the front wall of the fire-place, which ſerves occaſionally for cleaning out the fire-place, and the opening by which the flame paſſes from the fire-place into the kiln. This opening, which muſt never be quite cloſed, ſerves likewiſe for admitting a ſmall quantity of air to paſs horizontally into the fire-place. A ſmall proportion of air admitted in this manner has been found to be uſeful and even neceſſary in fire-places in which, in order to conſume the ſmoke, the flame is made to deſcend. Several ſmall holes for this purpoſe, fitted with conical ſtoppers, may be made in different parts of the front wall of the fire-place.

The bottom of the fire-place is a grate conſtructed of bricks placed edgewiſe, and under this grate there is an aſh-pit; but as no air muſt be permitted to paſs up through this grate into the fire-place, the aſh-pit door, *c*, is kept conſtantly cloſed, being only opened occaſionally to remove the aſhes.

d is the opening by which the lime is taken out of the kiln; which opening muſt be kept well cloſed, in order to prevent a draught of cold air through the kiln.

As only as much lime muſt be removed at once as is contained in that part of the kiln which lies below the level of the bottom of the fire-place, to be able to aſcertain when the proper quantity is taken away, the lime, as it comes out of the kiln, may be directed into a pit ſunk in the ground in front of the opening by which the lime is removed, this pit being made of proper ſize to ſerve as a meaſure.

While the lime is removing from the bottom of the kiln, freſh lime-ſtone ſhould be put into it above; and, during this operation, the fire may be damped by cloſing the top of the fire-place with its iron plate.

Should it be found neceſſary, the fire, and the diſtribution of the heat, may, in burning the lime, be farther regulated by cloſing more or leſs the opening at the top of the lime-kiln with a flat piece of fire-ſtone, or a plate of caſt iron.

The double walls of the kiln, and the void ſpace between them, as alſo the horizontal layers of bricks by which they are united, are clearly and diſtinctly expreſſed in the Figure. The kiln is repreſented as being nearly filled with ſmall round ſtones, ſuch as are uſed at Munich in burning lime. Theſe ſtones are brought down from the calcareous mountains on our frontiers, by the river (the Iſar), and are rounded by rubbing againſt each other as they are rolled along by the impetuoſity of the torrent.

END OF THE SIXTH ESSAY.